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VISIBILITY IN CALIFORNIA

Final Report

by

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ABSTRACT

This report characterizes various features of visibility in California using prevailing visibility measurements at 67 weather stations in conjunction with data on particulate concentrations and meteorology. The study addresses the issues of data quality, visibility/meteorology relationships, spatial visibility patterns, seasonal visibility patterns, diurnal visibility patterns, visibility/aerosol relationships, and historical visibility trends.

The weather station visibility data prove to be of very good quality for most of the analyses conducted herein; the only major data quality problem arises in the investigation of long-term historical trends. It should be noted, however, that -- because of the nature of reporting practices at weather stations -- special techniques must be applied in determining the statistical distribution of the data and in calculating visibility percentiles (e.g. medians).

The most important meteorological parameters with respect to visibility are relative humidity, temperature, and special weather events (especially fog), all three of which correlate negatively with visibility. It is found that very simple meteorological classification schemes can explain 80% of the temporal variance in visibility at given locations.

A detailed isopleth map based on all data (with no sorting for meteorology) reveals severe spatial gradients in visibility within California. The part of California along the Nevada border experiences among the best visibility in the nation (yearly median exceeding 70 miles), but California also contains two major pockets of very low visibility, the Los Angeles basin (yearly median less than 10 miles) and the San Joaquin Valley (yearly median less than 15 miles). An analysis of spatial patterns in emissions data, ambient particulate data, and meteorologically stratified visibility data indicates that these two major pockets of low visibility are basically caused by poor air quality rather than natural factors.

Minimal visibility in southern California and along the central coast occurs during the summer or spring, while minimal visibility in the Central

Valley, San Francisco region, and areas to the north and east occurs during the fall or winter. Sites in the Los Angeles basin display extremely low median visibilities (5 to 7 miles) during the summer; sites in the San Joaquin Valley exhibit extremely low median visibilities (6 to 7 miles) during the fall. The seasonal visibility patterns appear to be produced by seasonal air quality variations in the most man-affected areas (e.g. the Los Angeles basin and San Joaquin Valley) and by natural factors in the cleanest areas.

The diurnal pattern of visibility at most California locations seems to be dominated by the diurnal pattern of relative humidity; visibility is usually at a minimum during the early morning and increases during the day. When the data are sorted for meteorology, however, maximum visibility tends to occur in the morning, with minimum visibility at mid-day. This latter pattern agrees with the expected diurnal variations in aerosol concentrations.

Regression analyses relating visibility to relative humidity and aerosol concentrations produce high levels of correlation (.75 to .90) and physically reasonable regression coefficients. Averaged over 12 locations, the results indicate that sulfates account for approximately 40% of visibility reduction, while nitrates (or related photochemical pollutants) and the remainder of TSP each account for slightly more than 25%. Further work is necessary, however, in order to resolve statistical problems in the regression models and to extend the analysis into more areas of California.

From 1950 to 1966, visibility deteriorated at most locations in California, especially at sites in or near the Central Valley. From 1966 to 1975 nearly all California sites exhibited visibility improvement. The net effect from 1950 to 1975 was improvement in some areas (e.g. the central/coastal parts of the Los Angeles and San Francisco regions) but deterioration in other areas (e.g. the San Joaquin and southern Sacramento Valleys). Preliminary analyses indicate that the observed historical trends in visibility represent air quality changes rather than purely meteorological phenomena. Comprehensive data need to be compiled on long-term emission trends, however, before we can fully understand historical visibility trends.

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1.0 INTRODUCTION AND SUMMARY

One of the most readily apparent effects of air pollution, visibility degradation, is receiving increased attention from researchers because it may be closely related to some of the most damaging effects of air pollution. Two obvious types of damage associated with visibility impairment are aesthetic/psychological costs and hindrance of aviation. There has also been speculation, partly supported by theory and data relevant to the Northeast United States, that haze levels may play a significant role in climate modification. Finally, if (as several researchers have proposed) visibility is closely related to atmospheric sulfate and nitrate concentrations, then haze is linked with other sulfate and nitrate problems, such as acid rain and, possibly, health effects.

Visibility degradation is an especially important air quality issue in California where mountain ranges frequently offer exceptional panoramas. Concern is often expressed over the intense haze that can be found in major metropolitan areas such as Los Angeles. It is also a common public opinion that visibility levels have deteriorated in some of the less urbanized areas of California, and there is apprehension that future growth and development will lead to further visibility degradation.

The concerns over visibility degradation, both nationwide and in California, are reflected in the 1977 Clean Air Act Amendments wherein Congress established as a national goal "the prevention of any future and the remedying of any existing impairment of visibility in mandatory Class I Federal areas, which impairment results from manmade pollution". The Environmental Protection Agency (EPA) is now developing regulations for implementing a national visibility program (Federal Register 1979a). As mandated by Congress, EPA's regulations will require State Implementation Plans to include best available controls for both new and existing major sources likely to impair visibility in Class I areas. The regulations will also require State Implementation Plans to include a 10 - 15 year strategy for making reasonable progress toward the visibility goal.

The national visibility regulatory program will have significant effects on air quality planning in the state of California. Of the 156 mandatory Class I Federal areas where EPA has judged visibility to be an important value (Federal Register 1979b), 29 areas are located in California. In future State Implementation Plans, the California Air Resources Board will be faced with the problem of formulating visibility protection plans for these 29 areas (and possibly for additional areas that may be redesignated Class I).

Because visibility is an important air quality concern in California, and because technical information is needed to support visibility provisions in future State Implementation Plans, the Air Resources Board has contracted with Technology Service Corporation to conduct a comprehensive study of existing visibility data for California. The objectives of this study, for which this document serves as a final report, are as follows:

- Documentation of the availability and quality of weather-station visibility data, and formulation of procedures for meteorologically stratifying visibility data.
- Characterization and explanation of geographical patterns in visibility throughout California.
- Description and analysis of seasonal variations in visibility.
- Description and analysis of diurnal variations in visibility.
- Characterization of the relationship between visibility levels and aerosol concentrations, and formulation of haze budgets allocating visibility impairment among various aerosol components.
- Description and analysis of long-term (27 year) trends in visibility, and investigation of the possibility that changes in haze levels have noticeably affected climate.

The six sets of objectives listed above are the subjects of Chapters 2 through 7, respectively. The remainder of the present chapter provides an introduction to the basic technical concepts of visibility, a summary of the findings and conclusions reached during this study, and recommendations for future research.

1.1 BASIC CONCEPTS AND DEFINITIONS

Visibility refers to the clarity of the atmosphere and can be defined quantitatively in terms of discoloration (wavelength shifts produced by the atmosphere), contrast (the relative brightness of visible objects), and/or visual range (the farthest distance that one would be able to distinguish a large black object against the horizon sky). Because this study is based on weather-station measurements of visual range, we will define visibility as visual range and will use the two terms interchangeably. It should be noted that the concept of visual range makes most sense in situations of large-scale homogeneous haze, which is the type of visibility phenomenon being addressed in this report.

Visibility through the atmosphere is restricted by the absorption and scattering of light by both gases and particles. The sum of absorption and scattering is called total extinction which is measured by the extinction coefficient "B". The extinction coefficient represents the fraction of light that is attenuated per unit distance as a light beam traverses the atmosphere. In a homogeneous atmosphere, visibility is inversely proportional to extinction. For a standard observer (one able to perceive a two percent contrast), the Koschmeider formula expressing this relationship is:

$$B = \frac{24.3}{V} \tag{1-1}$$

where the units of visibility (V) are [statute miles], and the units of B are [10^{-4}meters^{-1}] the standard units for extinction. Examples of average visibility in certain areas and corresponding extinction coefficients are listed in Table 1.1.

It is often preferable to discuss visibility in terms of extinction coefficient rather than visual range because the extinction coefficient can be linearly subdivided into contributions from various atmospheric components. In general, total extinction is a linear sum of four terms:

$$B = B_{Rayleigh} + B_{Ab\text{-}Gas} + B_{Scat\text{-}Part} + B_{Ab\text{-}Part}$$

Here, $B_{Rayleigh}$ = light scattering by air molecules (Rayleigh or blue-sky scatter). This term is on the order of .10 to .12

TABLE 1.1 VISIBILITIES AND EXTINCTION COEFFICIENTS TYPICAL OF VARIOUS AREAS.

VISIBILITY (MILES)	EXTINCTION COEFFICIENT (10^{-4} m^{-1})	EXAMPLES OF AREAS EXHIBITING THIS AVERAGE VISIBILITY
8	3.04	Central/eastern part of the Los Angeles Basin.
10	2.43	Fringes of the Los Angeles Basin, or metropolitan centers in the Northeast, or large-scale haze in the Ohio Valley.
12	2.03	San Joaquin Valley of California, or large-scale haze typical of most nonurban areas east of the Mississippi and south of the Great Lakes.
20	1.22	Delta region east of San Francisco, or the Central Plains states (Minnesota, Iowa, and the eastern parts of Nebraska, Kansas, Oklahoma, and Texas).
50	0.49	Northeast plateau of California, or the area along the California-Arizona border, or the northern mountain states (Idaho and Montana).
80	0.30	Area along the California-Nevada border, or the southern mountain/desert states (Nevada, Utah, Colorado, northern New Mexico, and northern Arizona).
200	0.12	Air at sea level free of all particles and all pollutant gases.
250	0.10	Air at 5000 feet altitude free of all particles and all pollutant gases.

$(10^4 m)^{-1}$ depending on altitude (i.e., depending on the density of air); it would restrict visibility to approximately 200-250 miles if all particles and pollutant gases were absent.

B_{Ab-Gas} = light absorption by gases. Nitrogen dioxide (NO_2) is the only prevalent gaseous pollutant that is a significant light absorber. Although concentrations of NO_2 are usually not large enough to produce significant reductions in overall visual range, NO_2 can produce significant brownish discoloration because it preferentially absorbs blue light.

$B_{Scat-Part}$ = light scattering by particles (aerosols). In most cases, this is the dominant part of total extinction and therefore the main contributor to reduced visual range.

$B_{Ab-Part}$ = light absorption by particles. This term can become substantial in those areas where black soot constitutes a significant fraction of the aerosol.

As noted above, light scattering by particles usually dominates total extinction in hazy air masses. The two major exceptions are remote areas of the Rocky Mountain Southwest (including the California-Nevada border region) where natural blue-sky scatter is comparable to light scattering by aerosols, and certain urban areas where absorption by soot particles may be comparable to light scattering by aerosols.

1.2 SUMMARY

The following subsections summarize our findings and conclusions concerning visibility in California. For convenient referral, the summary is organized according to the order of the chapters.

Description of the Data Base

The visibility data presented in this report consist of routine prevailing visibility measurements made at weather stations (usually airports).

Because daytime and nighttime visibility measurements are often incompatible, and because the daytime data are usually of higher quality, only daytime observations are used throughout the report. Before sites were selected for the study, telephone surveys were conducted with visibility observers to insure that each weather station had an adequate set of visibility markers for estimating visual range. Based on this survey, 67 locations were chosen for the analysis.

Of the 67 study locations, data were available in computerized form for 21 sites and in hard-copy form (micro-fiche) for 46 sites. All 67 locations are used to characterize the geographical and seasonal patterns of existing visibility (based on 1 PM data for the years 1974-1976). Only the sites with computerized data could be used for other analyses such as visibility/meteorology relationships, meteorologically stratified spatial/temporal patterns of visibility, and long-term visibility trends.

There are several indications that the airport visual range data are of very good quality for use in analyzing geographical-seasonal-diurnal patterns of visibility, visibility/meteorology relationships, and visibility/aerosol relationships. The only major problem with the quality of the visibility data arises in the investigation of historical trends; artificial jumps in the trend data can be produced by changes in observation locations and/or reporting practices. Although procedures are formulated herein to help minimize this problem, the presence of artificial jumps in the hisotrical trend data nevertheless remains an important data quality concern.

Several of our analyses use routine Hi-Vol sampler measurements of TSP (total suspended particulate mass), sulfates, and nitrates in conjunction with the visibility data. The most important limitation of the particulate data is the severe measurement problem (artifacts and interferences) associated with nitrates.

Our descriptions of the patterns in visibility data are based on percentiles of visual range, usually the 50th percentile (median visibility), but sometimes also the best-case 10th percentile and worst-case 90th percentile. Because of the nature of reporting practices at weather stations, special techniques must be applied in determining the statistical distribution of the data and in calculating visibility percentiles. Application of the appropriate techniques makes the data consistent from site to site even if the various stations have visibility markers at different distances.

In order to gain an understanding of visibility/meteorology relationships and to develop an appropriate procedure for meteorological stratification of the visibility data, an extensive investigation is conducted regarding the dependence of visibility on meteorology. The investigation uses a very general and powerful statistical technique, decision-tree analysis, to relate visibility to meteorological parameters.

The most obvious meteorological conditions associated with low values of visibility (high values of extinction coefficient) are discrete weather events -- especially fog, but sometimes precipitation or blowing dust. Of the continuous weather parameters, relative humidity and temperature (both of which correlate negatively with visibility) are most important. Wind speed and ceiling height also bear significant relationships to visibility.

To reduce the statistical variance caused by meteorology, and to help separate man-made visibility impacts from natural visibility effects, procedures are developed for meteorological stratification of the visibility data. After formulating and evaluating numerous meteorological classification schemes, the following four-class scheme is selected:

- Class I: fog, precipitation, blowing dust/snow, or wind speed > 12 knots.
- Class II: non-Class I and relative humidity < 40%.
- Class III: non-Class I and 40% ≤ relative humidity < 70%.
- Class IV: non-Class I and 70% ≤ relative humidity.

This meteorological classification scheme explains about 80% of the variance in the extinction (visibility) data.

Geographical Patterns of Visibility

Using 1:00 PM data for 1974-1976 at 67 locations, a detailed isopleth map is prepared illustrating the geographical patterns of visibility throughout California. Because this map is based on all data (with no sorting for meteorology), the spatial visibility patterns represent both climatological variations and air quality variations. The map reveals that the spatial gradients of visibility in California are far more severe and complex than those observed anywhere else in the United States. Some parts of California exhibit among the best visibilities in the nation, while other parts experience among the worst visibilities in the nation.

The clearest air in California occurs along the Nevada border. One area along the border, Death Valley National Monument and the mountainous areas immediately northwest, experiences median visibility exceeding 70 miles. This area is on the fringe of a large region in the desert/mountain southwest United States which exhibits the highest visibilities in the nation.

Median visibility is also quite good, 45 to 70 miles, in the plateaus and mountains of northern California, the mountains of central-eastern California, the desert near the Arizona border, and the Vallecitos Mountains east of San Diego. To the west of all these areas, very sharp gradients occur, with visibility falling to less than 15 miles along the entire coastline except the far northern coast near Oregon, where median visibility falls to less than 25 miles.

Two significant pockets of poor visibility occur between the coast and eastern California. Median visibility is less than 15 miles in the large area consisting of the central/southern San Joaquin Valley. Visibility is less than 10 miles in the center of the Los Angeles basin.

A comparison of the spatial variations in visibility with the spatial variations in ambient particulate concentrations reveals good qualitative agreement between visibility patterns and the concentration patterns for sulfate and nitrate. The San Joaquin Valley and South Coast Air Basins, the two major pockets of low visibility, are obvious hot-spots for sulfate and nitrate. Although TSP concentrations also tend to be highest in the San Joaquin Valley and South Coast Air Basins, the spatial patterns in TSP do not generally seem to correspond as well with the visibility variations as do the spatial patterns in sulfate and nitrate.

The spatial patterns of anthropogenic emissions, ambient aerosol concentrations, and climatology suggest that the two major pockets of low visibility in California are caused by air quality variations rather than purely natural factors, such as fog, relative humidity, or precipitation. The extremely low visibilities in the central and eastern parts of the South

Coast Air Basin are likely caused by the high concentration of SO_x. NO_x, hydrocarbon, and particulate emissions in that air basin, with the problem exacerbated by relatively low wind speeds, strong inversion layers, and intense sunlight (leading to high production rates for photochemical aerosols). The large pocket of low visibility in the central/southern San Joaquin Valley may be related to several factors: (1) the high level of SO_x emissions in that area, (2) the relatively long residence times of air parcels in the San Joaquin Valley which allows greater time for secondary aerosols to form and accumulate, (3) the transport of secondary aerosol precursors from the San Francisco Bay Area, and (4) particulate matter from agricultural burning and dust sources.

The spatial variations in visibility east of the San Francisco Bay Area suggests that the principal visibility impact of Bay Area emissions may tend to be a diluted effect occurring downwind in the Central Valley rather than a concentrated effect occurring locally. Although the greatest visibility impact of emissions in the Los Angeles basin occurs within the basin, it appears that visibility deterioration from Los Angeles sources extends well into the Southeast Desert Air Basin.

Isopleth maps for worst-case 90th percentile visibility and best-case 10th percentile visibility display the same general spatial patterns as the map for median visibility. Specifically, the best visibility occurs along the California-Nevada border; visibility generally declines as one moves from the eastern borders toward the coast; and two significant pockets of low visibility, the South Coast and San Joaquin Valley Air Basins, occur between eastern California and the coast. One major difference among the visibility percentiles is that worst-case visibility exhibits more severe spatial gradients than median visibility which in turn shows stronger spatial gradients than best-case visibility. A corollary of the less intense spatial gradients in best-case 10th percentile visibility is that nearly all parts of California experience at least a few very clear days.

In order to gain a better understanding of natural versus man-made influences on visibility, an isopleth map is prepared with visibility data stratified according to meteorology (using meteorological Class III). In far-northern California, the meteorologically sorted data exhibit milder coast-to-inland gradients than the unsorted data; this indicates that some, if not most, of the coast-to-inland gradient in far-northern California is due to natural factors such as fog and relative humidity. Meteorological stratification slightly intensifies the pockets of poor visibility in the Los Angeles basin, San Joaquin Valley, and southern Sacramento Valley; this strongly supports our hypothesis that the low visibility in these areas stems primarily from man-made sources.

Seasonal Patterns of Visibility

Seasonal patterns in median 1:00 PM visibility are documented using all data (with no sorting for meteorology) for the years 1974-1976 at the 67 study locations. The data are divided according to the four calendar quarters: Jan. - Mar. (winter), Apr. - Jun. (spring), Jul. - Sept. (summer), and Oct. - Dec. (fall). It is found that the seasonal pattern in visibility is not uniform throughout California. The seasonal patterns are usually consistent, however, within individual air basins and major geographical sections of California.

Nearly all locations in southern California and along the central coast -- the South Coast, San Diego, Southeast Desert, South Central Coast, and North Central Coast Air Basins -- exhibit minimum visibility during the spring or summer (especially the summer), and maximum visibility during the fall and winter. Nearly all locations in the San Joaquin Valley, Sacramento Valley, and San Francisco Bay Area Air Basins display minimum visibility during the fall and winter and a distinct maximum during the spring; a similar pattern exists in the Northeast Plateau Air Basin (as well as some locations in the North Coast and Lake Tahoe Air Basins), except that maximum visibility is usually displaced from the spring to the summer.

Maps are prepared illustrating the geographical distribution of median visibility for each of the four seasons. Many significant changes in the spatial distribution of visibility are evident from season to season. The most notable seasonal variations involve the two major pockets of poor visibility, the South Coast and San Joaquin Valley Air Basins. During the summer, nearly the entire South Coast Air Basin experiences median visibility less than 7 miles, and the central/eastern part of the basin exhibits a median of approximately 5 miles. The San Joaquin Valley experiences minimal visibility during the fall, when the central/southern parts of the valley exhibit median visibilities of 6 to 7 miles, and an area of less than 10 miles visibility extends northward into the southern Sacramento Valley.

The causes for the seasonal patterns of visibility are analyzed by compiling data on seasonal variations in aerosol concentrations and by stratifying the seasonal visibility data according to meteorology. The analysis indicates that, at those locations where man-made visibility impacts are most severe (i.e. the South Coast and San Joaquin Valley Air Basins), the seasonal visibility patterns appear to be closely related to seasonal air quality variations (especially variations in sulfate and nitrate). For example, the winter/fall visibility minimum in the San Joaquin Valley is reflected in a winter/fall maximum for sulfate and nitrate; also, the meteorologically sorted visibility data for the San Joaquin Valley exhibit an even more pronounced winter/fall minimum than do the raw data. At those locations with lesser man-made impacts, i.e. the small coastal cities and northeastern California, the seasonal visibility patterns appear to be more closely tied to natural factors.

Diurnal Patterns of Visibility

Diurnal patterns in visibility are examined for the four daytime hours (7 AM, 10 AM, 1 PM, and 4 PM PST) in the computerized weather records. The initial analysis is performed using all the data (no sorting for meteorology). With the exception of the few far-inland/desert sites, basically all locations display a pattern of increasing visibility during the course of the day, with visual range about 20 to 60% higher at 4 PM than it is at 7 AM. At the far-inland/desert sites, visibility stays about constant or decreases during the day.

Based on physical reasoning, we expect that ambient particulate concentrations (both primary and secondary aerosols) should reach a maximum around mid-day. Although an extreme paucity of data exists concerning the diurnal pattern of aerosol concentrations, the few measurements that are available seem to support this expectation. Because visibility tends to increase during the day after a 7 AM minimum, we conclude that the daytime variation in aerosol concentrations is not the principal factor affecting the daytime variation in visibility.

The factor that controls the diurnal pattern of visibility at most locations appears to be relative humidity. In all areas of California, relative humidity tends to decrease substantially during the day, especially from 7 AM to early afternoon. The increase in visibility during the day at most locations is probably caused by the decrease in water associated with the aerosol, what the layman might call "burning off" of fog and haze by the sun. The reason why the far-inland/desert sites do not display the typical pattern of increasing visibility during the day is because the effects of relative humidity on aerosol light scattering are less important under dry conditions. With the relative humidity effect reduced in the desert, other factors (probably aerosol concentrations) become more significant to the diurnal visibility patterns.

A map is prepared illustrating the geographical distribution of the average time for minimum visibility. This map reveals an obvious coast-to-inland gradient. The time of minimal visibility averages approximately 9 - 10 AM at the coastal sites and 11 - 12 AM at the far-inland/desert sites. The explanation for this spatial pattern is that relative humidity effects -- which tend to produce minimum visibility early in the morning (i.e. at the 7 AM observation) -- are most important along the coast. As one proceeds inland, the diurnal patterns of aerosol concentrations become of greater significance as the relative humidity effects diminish in significance.

The spatial gradients in average time for minimal visibility are slightly more intense in the South Coast and San Francisco Bay Area Air Basins than at other locations. This likely reflects the phenomenon of pollution transport within the Los Angeles and San Francisco Air Basins under the daytime sea breeze.

Although serious difficulties arise in stratifying the diurnal visibility patterns according to meteorology, the meteorologically stratified data at nearly all sites do agree with our expectation concerning the mid-day peak in aerosol concentrations. Specifically, the meteorologically stratified visibility data tend to show a maximum in visibility at 7 AM (in contrast to the 7 AM minimum for the raw data) with a minimum around mid-day.

Visibility/Aerosol Relationships

Our analysis of visibility/pollutant relationships is based on statistical regression equations that relate daytime average extinction (determined from the visibility data) to daily averages of sulfates, nitrates, the remainder of TSP, and relative humidity. The coefficients of these regression equations can be interpreted as "extinction coefficients per unit mass" or "extinction efficiencies" for each aerosol species. These extinction coefficients allow us to estimate the fraction of haze (or fraction of visibility loss) attributable to each aerosol component.

There are several limitations to the use of regression models for quantifying visibility/aerosol relationships: (1) random errors in the data base caused by imprecision in the measurement techniques for airport visibility and aerosol concentrations; (2) incompatibilities between the airport data and the aerosol data which are collected at different locations and over different hours of the day; (3) biases in the measurement of sulfates and, especially, nitrates; and (4) statistical problems introduced by the intercorrelations among the "independent" variables (sulfates, nitrates, remainder of TSP, and relative humidity) and by correlations between these variables and other visibility-related pollutants omitted from the analysis. The most important limitations are the measurement errors for nitrates and the statistical problems. In fact, because of the difficulties associated with nitrates, it is best to regard the "nitrate" variable as a gross measure of both nitrate aerosols and related photochemical pollutants (such as secondary organic aerosols and NO_2). All of the above limitations must be kept in mind when interpreting the results of the regression analyses.

Visibility/aerosol regression models are completed for 12 locations: four in the South Coast Air BAsin; two each in the San Francisco Bay Area, San Joaquin Valley, and Sacramento Valley Air Basins; and one each in the San Diego and South Central Coast Air Basins. Two regression equations are used, a completely linear model and a model incorporating nonlinear relative humidity effects. At each location, the regression models are run on two data bases, one excluding days with precipitation or any fog, and the other excluding days with precipitation or severe fog.

For the data sets excluding days with precipitation or any fog, the regression models indicate that, averaged over the 12 sites, sulfates acount for approximately 40% of total extinction, while nitrates and remainder of TSP each account for slightly more than 25% of extinction. Sulfates seem to be relatively more important at the southern sites (the four SCAB locations and San Diego); nitrates appear to be relatively more important in the San Joaquin Valley; and the remainder of TSP seems to be relatively more important in the Sacramento Valley. The results are fairly similar for the data sets excluding days with precipitation or severe fog, except that the sulfate contributions are emphasized even more.

The regression analyses in this report, as well as similar studies found in the literature, indicate that the extinction coefficients per unit mass for secondary aerosols (sulfates and nitrates) are nearly one order of magnitude greater than the extinction coefficients per unit mass for the remainder of TSP. Qualitatively, this agrees with known principles of aerosol physics. Secondary aerosols tend to accumulate in the particle size range from 0.1 to 1 micron, while the remainder of TSP is usually dominated by the coarse particle mode residing in the size range above 2 microns. Light-scattering per unit mass of aerosol as a function of particle size exhibits a pronounced peak at a particle size of about 0.5 microns, and particles in the 0.1 to 1 micron size range scatter much more light per unit mass than particles above 2 microns in size.

Quantitatively, the extinction coefficients per unit mass obtained in empirical/regression studies tend to be slightly higher than theoretical values. There appear to be two factors causing this discrepancy: (1) differences in the daily time periods for measuring extinction (based on visibility data from 7 AM to 4 PM) and aerosol concentrations (based on 24-hour Hi-Vol data) and (2) statistical problems introduced by intercorrelations between the independent variables. The first factor is not critical to the computation of extinction budgets because a cancellation of effects occurs during the computation (the coefficients that are slightly biased high are multiplied by aerosol concentrations that are correspondingly biased low). The statistical problems, however, do adversely affect the extinction budgets.

Further work needs to be done in order to resolve the statistical problems in the visibility/aerosol regression analysis. The most promising approach would be to combine the statistical results with theoretical results and derive a general extinction equation that is applicable to all sites within a given area of California. In pursuing this approach, it will be necessary to run regression models for additional sites in each area of California.

Historical Visibility Trends

Long-term visibility trends are documented for the period 1949 to 1976 at 19 locations in-and-near California. Potentially serious data quality problems can occur in the historical trend analysis due to changes in reporting practices and/or observation locations at the weather stations. We have attempted to minimize these problems by restricting the analysis to station/years of uniform reporting practices, conducting statistical tests on the significance of site relocations, and examining trends at nearby locations for consistency.

Plots of long-term trends in median visibility (for all data with no sorting for meteorology) at the 19 study sites reveal that visibility trends in California tend to split into two general sub-periods, divided at approximately 1966. Before 1966, nearly all locations exhibit deteriorating visibility, with especially large visibility decreases occuring in-and-near the Central Valley. After 1966, nearly all locations display improving visibility.

The historical visibility trends are most easily summarized in a quantitative manner by examining changes in three-year averages of various visibility percentiles from 1949-1951 to 1965-1967 to 1974-1976. As noted above, most locations exhibited deteriorating visibilities from 1949-1951 to 1965-1967. In particular, Downtown Los Angeles, San Bernardino, Fairfield, Arcata, San Diego, Santa Maria, Bakersfield, Fresno, Sacramento, and Red Bluff displayed decreases in visibility on the order of 20 to 40%. The largest decreases occurred at locations in or near the Central Valley. The three notable exceptions during the period 1949-1951 to 1965-1967 are Long

Beach, Oakland, and San Francisco, which underwent moderate ($\sim$20%) improvements in visibility.

From 1965-1967 to 1974-1976, nearly all sites show visibility improvements on the order of 10 to 60%. The three exceptions are Sacramento, Stockton, and Yuma (AZ), which display little net change from 1965-1967 to 1974-1976.

Over the entire two and one-half decades from 1949-1951 to 1974-1976, the major areas experiencing a net improvement in visibility were the central/coastal parts of both the South Coast Air Basin and the San Francisco Bay Area Air Basin. The densely populated, central/coastal portions of these metropolitan regions underwent net improvements in visibility on the order of 10 to 40%. Slight improvements in visibility also seem evident in northeastern California and southern Oregon from 1949-1951 to 1974-1976. The major areas that experienced net deterioration in visibility -- on the order of 10 to 30% -- are the San Joaquin and southern Sacramento Valleys, the South Central Coast Air Basin, the inland part of the South Coast Air Basin, and the Southeast Desert Air Basin.

For Downtown Los Angeles, we are able to determine visibility trends from 1933 to 1976 using data assembled by Ralph Keith (1970, 1979a). As noted by Keith, we find that visibility at Downtown Los Angeles has gone through cycles: a sharp deterioration during the industrial expansion of the early 1940's; significant improvement with the onset of air pollution controls in the late 1940's and early 1950's; gradual deterioration from the early 1950's to the early 1960's as growth (especially in automotive traffic) evidently outstripped stationary source controls; and improvement from the middle 1960's to the middle 1970's as automotive controls came into effect and stationary source controls were further tightened. Comparing the middle 1930's to the early 1970's, it is obvious that the principal net change occurred on days of best visibility; the best 10th percentile decreased from about 40 miles to less than 25 miles. In contrast, median and worst-case 90th percentile visibilities have not exhibited much net change from the 1930's to the 1970's and may have even increased somewhat. It should be remarked that the long-term visibility trends at Downtown Los Angeles may be affected by meteorological cycles and undocumented changes in visibility reporting practices as well as by source growth and air pollution controls.

Visibility trends from 1949-1951 to 1965-1967 to 1974-1976 at the 19 study sites are also examined individually for the four quarters of the year. The one outstanding seasonal feature in the trends is the deterioration of winter/fall visibility relative to spring/summer visibility in the San Joaquin and Sacramento Valleys. During the early 1950's, winter and fall median visibility in the Central Valley were about the same as summer median visibility and slightly worse than spring median visibility. By the middle 1970's, winter and fall median visibilities fell to about two-thirds of summertime values and about one-half of springtime values. It should be noted that the winter and fall seasons in the Central Valley are most sensitive to anthropogenic air quality changes (especially with respect to secondary aerosols) because the winter/fall period is the prime season for stagnant air and high relative humidity (which can promote secondary aerosol formation and accumulation).

Historical visibility trends are also analyzed with data stratified according to meteorology. The meteorologically sorted trends are very similar to the trends based on all the data. This suggests that the historical visibility changes most likely represent air quality changes rather than purely meteorological phenomena such as fog, precipitation, blowing dust/snow, or relative humidity. Specifically, the general deteriorating trend in visibility from 1949-1951 to 1965-1967 may be related to emission source growth, while the improving level from 1965-1967 to 1974-1976 may be related to emission control programs. It should also be noted that the meteorologically stratified visibility data exhibit the same strong seasonal trends in the Central Valley as do the raw trend data.

It is difficult to reach firm conclusions regarding the specific causes of historical visibility trends without long-term data on pollutant trends. Data on <u>ambient</u> aerosol trends are not of great help for interpreting visibility changes because the ambient data cover a relatively short time period, because historical ambient data are available only for a few locations, and because serious statistical and measurement problems arise in using the ambient data for long-term analysis. The best possibility for documenting long-term ($\sim$30 year) pollutant trends is to conduct a study of historical emission trends for primary aerosols and for precursors of secondary aerosols. An analysis of 30-year emission trends for various regions in California would be a useful subject for future work.

Other investigators have speculated that historical visibility changes in the Northeast United States may have caused significant climatic changes; in particular, increases in haze may have reduced daily maximal temperatures by as much as 4^0F. To see if such effects might be occurring in California, we examined temperature changes at various locations during sub-periods of 1949-1976 that exhibited strong visibility changes. We were able to find no relationship between historical visibility changes and historical temperature changes. Although these results do not prove that haze levels have little effect on temperature in California, our results do suggest that the relationship between haze and temperature is not as strong or as obvious as one might have suspected based on the data for the Northeast United States.

1.3 NEEDS FOR FUTURE WORK

This study of visibility in California has pointed out two critical areas for future research. The first is to expand and improve our analysis of visibility/aerosol relationships. In order to correct some of the deficiencies in our empirical analysis produced by statistical problems in the regression models, a synthesis should be made of empirical and theoretical results to derive hybrid visibility/aerosol models specific to individual parts of California. In deriving such models, regression analyses must be performed for several sites in addition to the ones studied here. It would also be worthwhile to add more terms to the regression equations by using chemical element tracer methods to further separate out individual fractions of the aerosol. This first area of needed research is presently being pursued in a contract that the Air Resources Board recently awarded to Technology Service Corporation.

The second area for future research involves compilation of long-term emission trends. In order to understand the causes of historical visibility trends in California, we need quantitative information on historical emission changes for primary aerosols and precursors of secondary aerosols. No such information -- based on a consistent data base for uncontrolled emission factors, historical control factors, and source growth factors -- is available for California. Recent studies for other states, however, have shown that it is possible to trace historical emissions for 30 years or more into the past. A detailed analysis of long-term emission trends for various regions in California should be regarded as a promising area for future research.

2.0 DESCRIPTION OF THE DATA BASE

Before proceeding with our investigation of visibility in California, it is worthwhile to describe the visibility data base that serves as the foundation for our study. This chapter discusses the data base, consisting of routine visibility observations taken at weather stations (mostly airports), and explains some of the general procedures used in processing the data. Section 2.1 describes the visibility observations, indicates the study locations, and reviews data quality. Section 2.2 explains the special techniques that must be applied in order to determine the statistical distribution of visibility from airport data. Section 2.3 examines the dependence of visibility on meteorology and discusses the procedures used to stratify the data for meteorology in some of our analyses.

2.1 WEATHER STATION VISIBILITY DATA

The visibility data presented in this report consist of "prevailing visibility" recordings made by weather station observers. According to National Weather Service procedures, prevailing visibility is defined as the greatest visual range that is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors (Williamson 1973). Daytime visibility is measured by observing markers (e.g. buildings, mountains, towers, etc.) against the horizon sky; nighttime visibility measurements are based on unfocused, moderately intense light sources. Because our experience indicates that daytime and nighttime observations are often incompatible, and that the daytime data are usually of higher quality (Trijonis and Yuan 1978a, b), only daytime observations are used throughout this study.

Weather observers usually perform visibility measurements each hour. In recent years, however, only the readings from every third hour are entered into the National Climatic Center computerized data base.* In characterizing the geographical and seasonal patterns of existing visibility levels, we restricted our analysis to the 1:00 PM PST observations. A single hour

*In the Pacific Time Zone, these hours are 1:00 AM, 4:00 AM, ..., 10:00 PM, standard time.

was used each day because most of the data for characterizing existing visibility levels were available only in hard copy (micro-fiche), and limiting the analysis to one hour per day saved considerable work in hand-processing such data. For several studies that were conducted with computerized data -- e.g. visibility/meteorology relationships, diurnal patterns, visibility/aerosol relationships, and long-term historical trends -- all four daytime measurements (7:00 AM, 10:00 AM, 1:00 PM, and 4:00 PM) were used.

The various analyses that we conducted on existing visibility levels are based on data for the three-year period 1974 to 1976. Three years provides a robust, yet manageable, amount of data. The studies of long-term historical trends essentially cover the period 1949 to 1976.

2.1.1 Study Locations

Before sites were selected for this study, telephone surveys pertaining to data quality were conducted with visibility observers at approximately 80 weather stations.* The purpose of these surveys was to insure that each station had an adequate set of visibility markers for estimating visual range. In particular, we attempted to choose sites that had farthest markers located at distances at least as great as the visibility levels typical of the surrounding area. Most of the locations selected do have good markers. In some cases, however, we were forced to use stations with less than optimal markers in order to attain good geographical coverage in the study; for these cases we had to extrapolate the cumulative frequency distributions in order to estimate median visual range (see discussion in Section 2.2).

Sixty-seven locations were selected for characterizing the spatial and seasonal patterns of existing visibility in California. The density of stations is quite high, considering that median visibility usually exhibits very gradual spatial changes (because prevailing visibility measurements represent averages over several miles). For example, we found that only 100 locations were adequate to describe the spatial patterns in nonurban visibility throughout the continental United States (Trijonis and Shapland

*Appendix A lists all the weather stations (144 sites) now operating in California. Appendix B lists those stations and years for which computerized data are available from the National Climatic Center.

1979). We require a greater density of stations in the present study because Califonia exhibits the strongest spatial gradients of visibility in the nation, and because this study considers urban as well as nonurban variations in visibility.

Figure 2.1 displays the 67 study locations, and Figure 2.2 illustrates their location within the California Air Basins. All of the locations are airports with the exception of Blue Canyon, Campo, Lakeview (Oregon), Newport Beach, Pillar Point, Sandberg, and San Francisco Pilot Boat. Figure 2.3 presents the altitudes of the study sites; as will be discussed later in Chapter 3, special allowances are made for the altitudes of several sites in constructing a map illustrating median visibility levels.

Of the 67 sites used to investigate the geographical and seasonal patterns of existing visibility, data for 46 sites were obtained in hard copy (micro-fiche). At the other 21 sites (the underlined locations in Figure 2.1), the availability of computerized data permitted several analyses in addition to spatial and seasonal patterns. The additional analyses conducted at these 21 sites (or subsets thereof) include visibility/meteorology relationships, meteorologically adjusted spatial patterns of visibility, meteorologically adjusted seasonal patterns of visibility, diurnal patterns of visibility (both for all data and meteorologically adjusted data), long-term visibility trends (both for all data and meteorologically adjusted data), and long-term effects of haze on temperature.

2.1.2 Data Quality

Previous studies (Trijonis 1979; Trijonis and Shapland 1979; Leaderer et al. 1979; Husar et al. 1979; Trijonis and Yuan 1978a, 1978b; Latimer et al. 1978) have found that airport visiiblity data are of very good quality for use in analyzing existing visibility levels, visibility/meteorology relationships, and visibility/aerosol relationships. This conclusion is confirmed in the present investigation. To give the reader a feel for the high quality of the visibility data used herein, we note the following:

- As discussed in Section 3.1, very good consistency is found in the spatial patterns of visibility levels. Monotonic gradients often exist in passing from areas of poor visibility to areas of

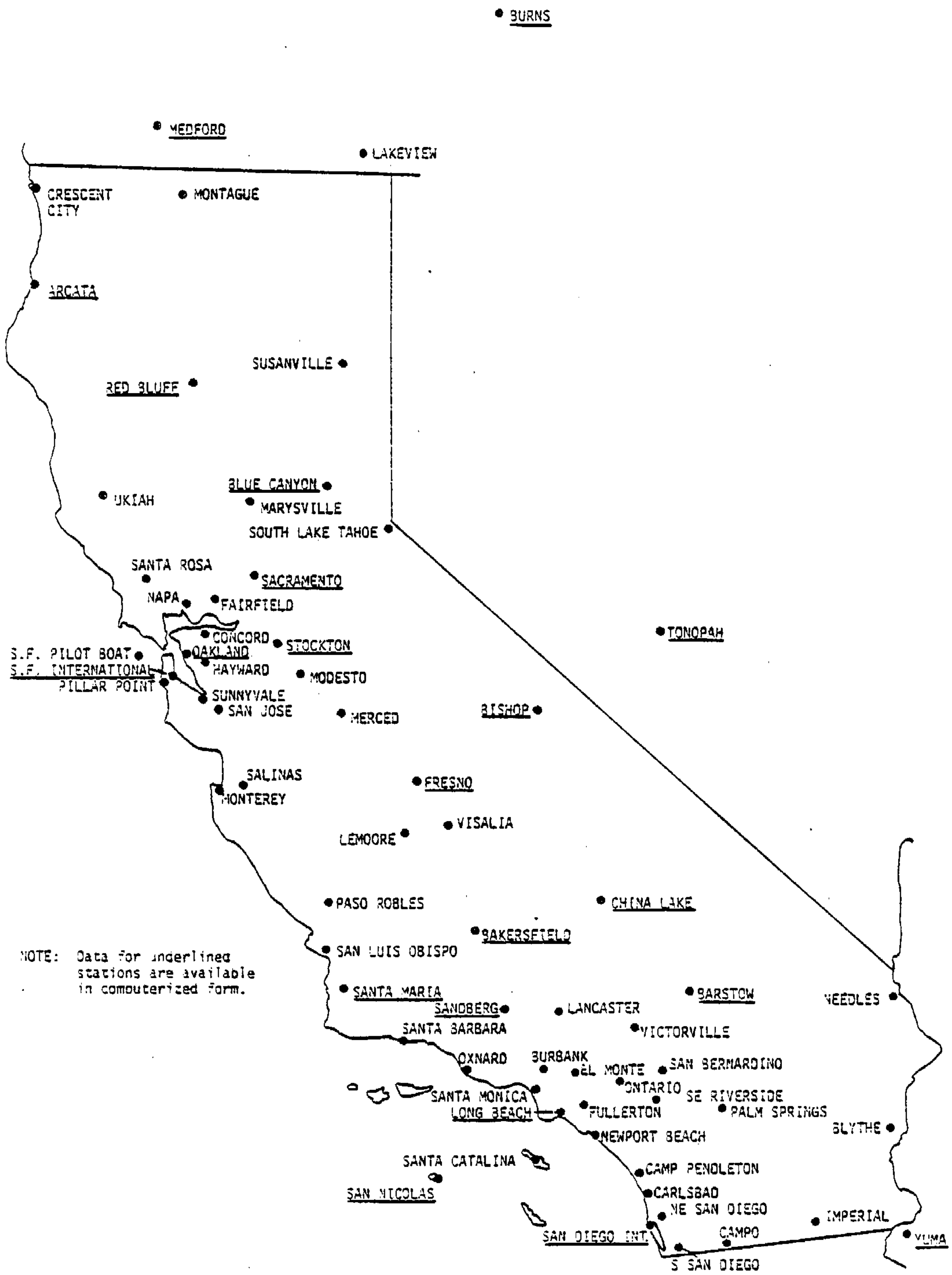

Figure 2.1 Weather stations used to characterize existing visibility in California.

Figure 2.2 California air basins and visibility study locations.

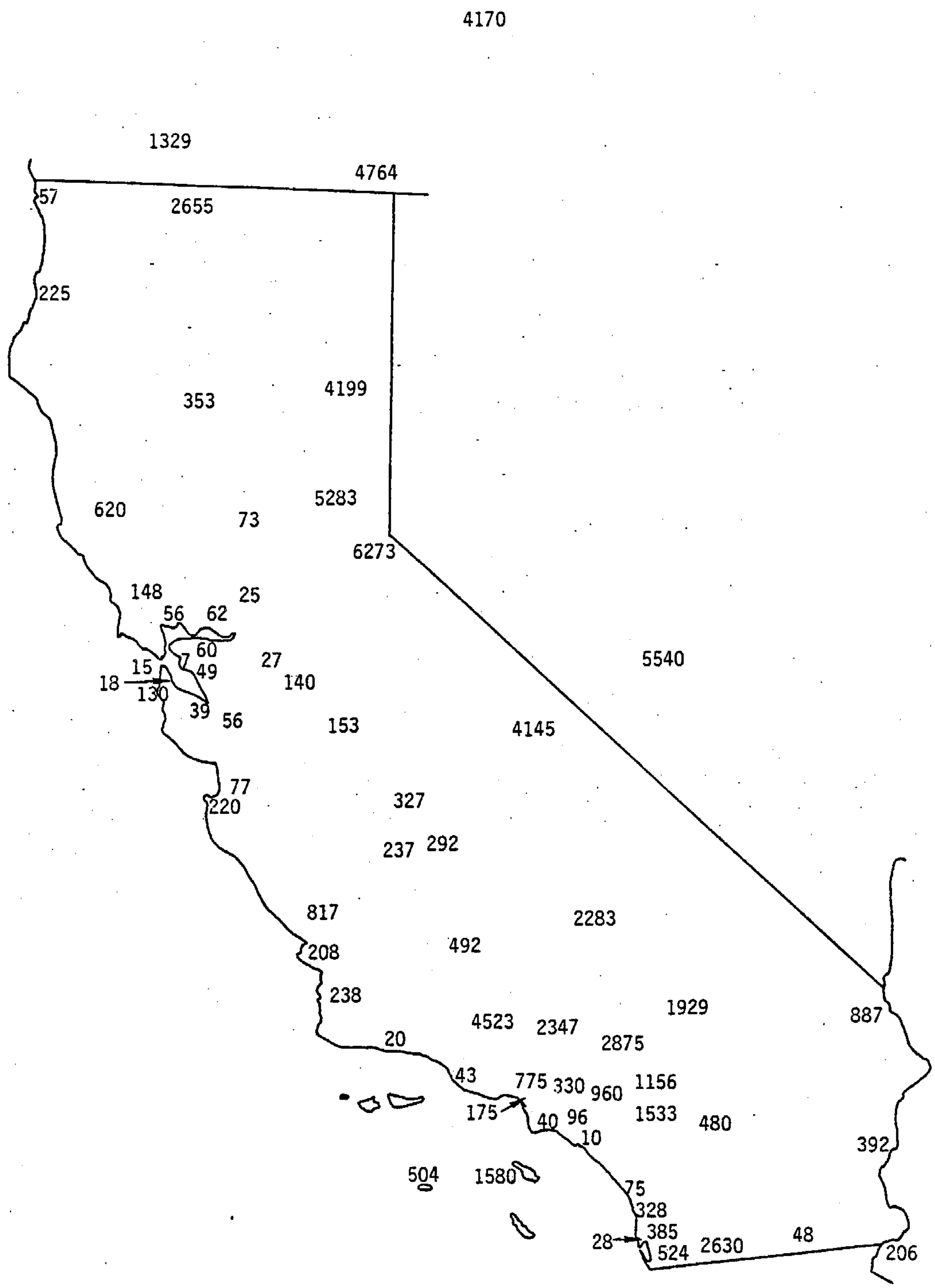

Figure 2.3 Altitudes of the visibility study locations (in feet).

good visibility, and the readings at neighboring stations tend to agree. As examples of this agreement, we note that the five study sites in the central part of the South Coast Air Basin all display median visibilities of 7 to 9 miles, and that the seven study sites in-and-near northeastern California all exhibit median visibilities of 45 to 65 miles. Good agreement also occurs in the seasonal patterns for neighboring stations.

- In Section 2.3, we find that dividing the data into general meteorological classes explains a very high percentage of the variance in extinction (i.e. the reciprocal of visibility). Typically, the correlation coefficient achieved by the meteorological stratification is on the order of 0.80 to 0.95 among the study sites. In order for such high correlations to be obtained between visibility and meteorological parameters, the visibility data must be of good quality.

- Regression analyses which relate extinction to aerosol concentrations and relative humidity (see Chapter 6) also achieve high levels of correlation, typically 0.75 to 0.90, again demonstrating the quality of the visibility data. These high correlations are obtained despite the facts that only a crude breakdown of the aerosol (i.e. Hi-Vol data for TSP, sulfates, and nitrates) is available, that the aerosol data themselves involve errors, and that the aerosol samplers and airports are usually located several miles apart.

The only major problem with the quality of the visibility data arises in the historical trend analysis. In examining historical trends, we are often dealing with actual long-term visibility changes of 20% or less. Variations of this magnitude may also be produced artificially by changes in observation locations and/or reporting practices. As discussed in Chapter 7, we have attempted to minimize these problems by documenting changes in reporting practices, by conducting statistical tests on changes in observation locations, and by examining trends at neighboring locations for consistency. Nevertheless, the presence of noise and artificial jumps in the historical trend data remains an important data quality problem.

2.1.3 Aerosol Data

In the analysis of visibility/aerosol relationships (Chapter 6), day-to-day variations in Hi-Vol data for TSP, sulfates, nitrates, and (when available) organics are correlated with day-to-day variations in visibility data. The aerosol data -- obtained from the National Air Surveillance Network (NASN), the California Air Resources Board, and the San Francisco Bay

Area AQMD -- are summarized in Table 2.1. These data and their limitations are discussed further in Chapter 6.

Aerosol data are also used for comparison purposes in several other parts of this report. Specifically, the geographical, seasonal, diurnal, and long-term variations in visibility are compared to corresponding variations in aerosol concentrations.

2.2 STATISTICAL DISTRIBUTIONS OF VISIBILITY DATA

In practice, a weather station visibility recording of X miles usually means that visual range is <u>at least</u> X miles rather than visual range is exactly X miles. For example, at a station with farthest visibility markers of 65 and 50 miles, a recording of 65 miles would imply that visual range was at least 65 miles, and a recording of 50 miles would imply that visual range was between 50 and 65 miles. Because of this phenomenon, weather station visibility observations are most appropriately summarized by cumulative frequency distributions of the form "percent of time visibility is greater than or equal to X miles". These cumulative frequency distributions are determined by noting the percent of time that visibility exceeds the farthest reported value, and then adding percentages cumulatively as one proceeds toward the smaller reported values. In this process, it is very important to use only those visibilities that are <u>routinely</u> reported by the weather observation team*; otherwise, artificial "kinks" will be produced in the cumulative frequency distribution. Summarizing the visibility data in the above way should make the data consistent from station to station even if the various stations have visibility markers at different distances.

Figure 2.4 presents examples of cumulative frequency distributions for four California locations which vary widely in observed visibilities (cumulative frequency distributions for 1974-1976 at all 67 study locations are presented in Appendix C). The dots in Figure 2.4 represent the routinely reported visibilities (often these correspond to distinct visibility

*Referring to the previous example (with the 65 and 50 mile markers), if one member of the observation team occassionally decided to report 55 mile visibility rather than the routine 50 miles, then the 55 mile recordings should be lumped with the 50 mile recordings in the cumulative frequency distribution.

TABLE 2.1 AEROSOL DATA USED IN THE VISIBILITY/ AEROSOL REGRESSION ANALYSES.

DATA SOURCE/LOCATIONS	YEARS OF DATA	AEROSOL SAMPLING TECHNIQUES			
		TSP	SULFATE	NITRATE	ORGANICS
NATIONAL AIR SURVEILLANCE NETWORK					
Burbank	1970-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
Fresno	1970-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
Long Beach	1967-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
Oakland	1966-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
Ontario	1970, 1972-1973	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
Sacramento	1968-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
San Bernardino	1968-1970	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
San Diego	1966-1974	Hi-Vol (glass filter)	Colorimetric	Reduction Diazo Coupling	
CALIFORNIA AIR RESOURCES BOARD					
Bakersfield	4/76-3/78	Hi-Vol (glass filter	Turbidimetric	Brucine Colorimetric	Benzene Extraction
Barstow	4/77-3/78	Hi-Vol (glass filter)	Turbidimetric	Brucine Colorimetric	
Paso Robles	4/76-3/78	Hi-Vol (glass filter)	Turbidimetric	Brucine Colorimetric	Benzene Extraction
Red Bluff	4/76-3/78	Hi-Vol (glass filter)	Turbidimetric	Brucine Colorimetric	Benzene Extraction
SAN FRANCISCO BAY AREA AQMD					
San Jose	1975-1977	Hi-Vol (cellulose filter - 1975; glass filter - 1976-1977)	Turbidimetric	Colorimetric	

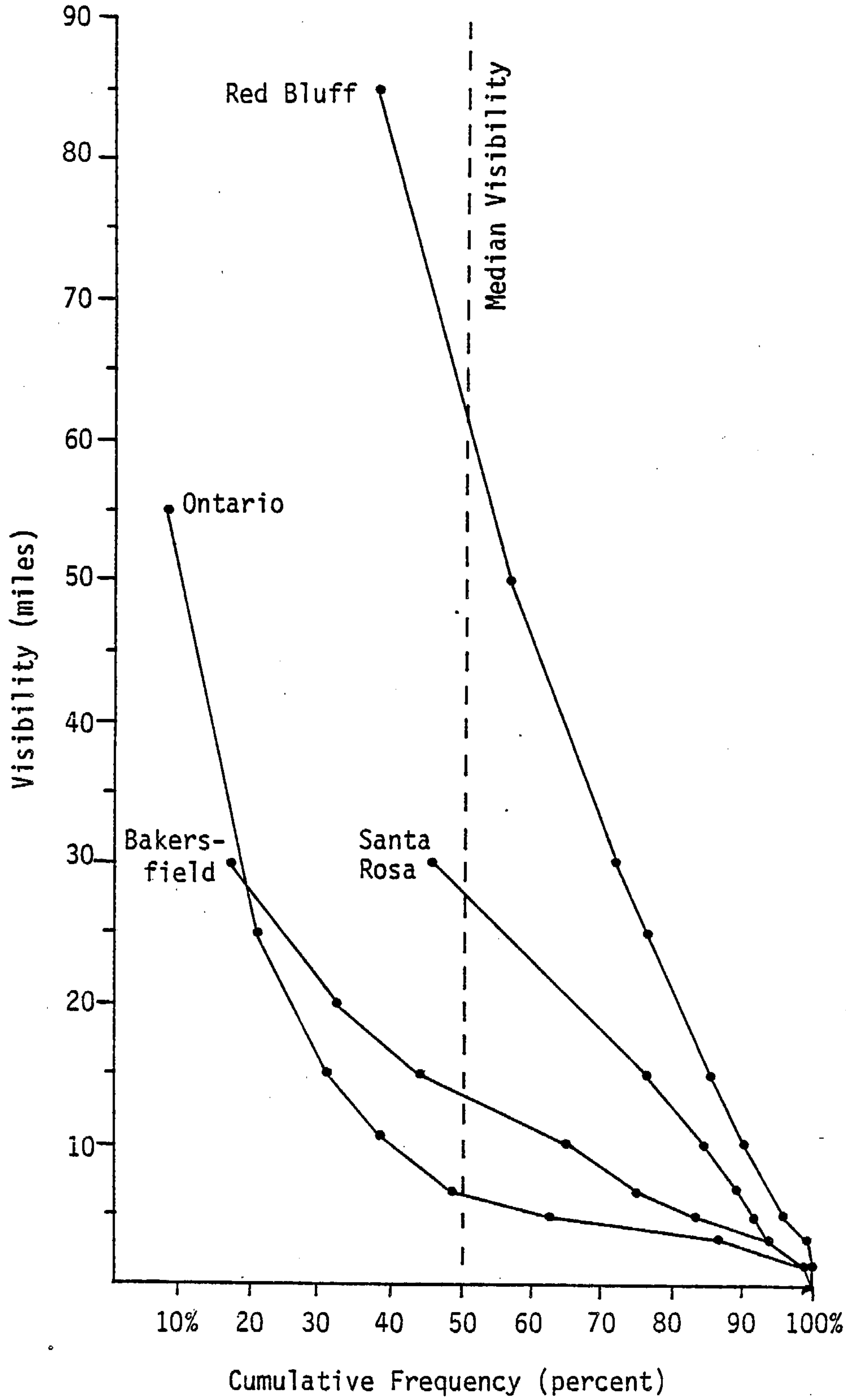

Figure 2.4 Examples of cumulative frequency distributions for visibility (1:00 PM data, 1974-1976).

markers). The lines drawn between the dots represent linear interpolations of the cumulative frequency distributions.

Most of our results concerning the spatial and temporal patterns of California visibility deal with median visual range. As is the case with the four locations illustrated in Figure 2.4, most of the median visibilities are determined by linear interpolations of the cumulative frequency distribution. In some cases, however, the frequency distributions required extrapolation in order to reach the median visibilities. The form of these extrapolations, linear or nonlinear, was based on a comparison of the distribution for the station in question with distributions for other sites located in the same general geographical area [including sites from our previous nationwide study (Trijonis and Shapland 1979)]. For stations where these extrapolations involve significant uncertainties, the uncertainties are noted throughout this report by asterisks placed on the estimated median visibilities.

2.3 VISIBILITY/METEOROLOGY RELATIONSHIPS

This section investigates the dependence of visibility on meteorology. The purposes are to gain an understanding of visibility/meteorology relationships and to develop an appropriate procedure for meteorological sorting of of the visibility data. Most of the analyses in subsequent chapters of this report are performed twice, once with all the visibility data, and once with meteorologically sorted data. Meteorological stratification of the data is useful because it helps to separate man-made influences from natural influences, and because it reduces the stochastic variance in the data.

The study of visibility/meteorology relationships is conducted for the 13 sites listed in Table 2.2. For convenience in organizing and discussing the results, the sites are grouped according to five types of location: Coastal-Metropolitan, Coastal-Rural, Northern Valley, Central Valley, and Desert. The analysis at each site is conducted using three years of data, 1974-1976.* All four daylight measurements are included, so there are 4384 data points at each location.

*The only exception is San Bernardino, where 1968-1970 are the latest three years with computerized records.

TABLE 2.2 LOCATIONS USED TO STUDY VISIBILITY/ METEOROLOGY RELATIONSHIPS.

COASTAL - METROPOLITAN	NORTHERN VALLEY
San Francisco (Int.)	Medford
Long Beach	Red Bluff
San Bernardino	
San Diego (Int.)	CENTRAL VALLEY
	Sacramento
COASTAL - RURAL	Fresno
Arcata	Bakersfield
Santa Maria	
	DESERT
	Bishop
	Yuma

Table 2.3 describes the 11 meteorological parameters used in the study. The meteorological data for each hour are extracted from the same National Climatic Center TDF 1440 tapes that supply the visibility data.

The study of visibility/meteorology relationships is performed with the visibility data transformed into extinction data using the Koschmeider formula, B = 24.3/V (see Section 1.1 for a discussion of the Koschmeider formula). Thus, the analysis actually pertains to extinction/meteorology relationships which should bear some resemblances to pollutant/meteorology relationships (because extinction tends to be linearly related to aerosol concentrations with all other factors held constant). In our statistical analyses, which focus on explaining the variance in the dependent variable, using extinction data rather than visibility data places greatest weight on worst-case conditions (i.e. high values of B) rather than best-case conditions (i.e. high values of V). When logarithims of extinction are used in the analysis, worst-case and best-case conditions are weighted more evenly.

TABLE 2.3 WEATHER PARAMETERS USED TO STUDY VISIBILITY/METEOROLOGY RELATIONSHIPS.

WEATHER PARAMETER (CODE)	DESCRIPTION	UNITS
Fog (FOG)	Occurrence of fog (0 = no, 1 = yes).	no units
Relative Humidity (REL HUMI)	Relative humidity in percent.	no units
Temperature (TEMP [F])	Dry bulb temperature.	^{o}F
Ceiling Height (CEIL HGT)	Distance to ceiling (sky cover of 60% or greater).	10^2 feet
Wind Speed (WIND SPD)	Surface wind speed.	knots
Sky Cover (SKY COVR)	Percent of celestial dome covered by clouds or obscurring phenomena.	no units
Blowing Dust (BLW DUST)	Occurrence of dust, blowing dust, or blowing sand (0 = no, 1 = yes).	no units
Liquid Precipitation (LIQUD PR)	Occurrence of rain, rain showers, freezing rain, rain squalls, drizzle, or freezing drizzle (0 = no, 1 = light, 2 = moderate, 3 = heavy).	no units
Frozen Precipitation (FROZN PR)	Occurrence of snow, snow pellets, ice crystals, snow showers, snow squalls, snow grains, sleet, sleet showers, or hail (0 = no, 1 = light, 2 = moderate, 3 = heavy).	no units
Blowing Snow or Spray (BLW SNOW)	Occurrence of blowing snow or spray (0 = no, 1 = yes).	no units
Thunderstorms (THUNDERS)	Occurrence of thunderstorm, tornado, or squall (0 = no, 1 = yes).	no units

2.3.1 Dependence of Extinction on Weather Parameters

In order to study the general relationship between extinction and weather parameters, we used the CART (Classification and Regression Trees) program developed at Technology Service Corporation (Brieman 1978). The purpose of the program is to explain the variation in a dependent variable (extinction) by sequentially splitting the data according to ranges of the independent variables (meteorological parameters). As illustrated in Figure 2.5, the net result is a decision-tree that accounts for the variance in the dependent variable according to groups (meteorological classes) defined by the independent variables.

For the problem of relating extinction to meteorological variables, the CART decision-tree program offers several advantages over more conventional data-analytic techniques such as multiple linear regression. The advantages include the following:

- The CART program is a non-parametric technique based on a general form of the least-squares principle; it does not involve restrictive assumptions such as additivity and linearity.
- The meteorological classes defined by CART can be interpreted on physical grounds more easily than multivariate regression equations.
- Because the CART trees are evaluated by a cross-validation test with independent data sets, an unbiased estimate is obtained of the percent variance explained.
- Previous experience (Trijonis et al. 1979) indicates that decision-tree analysis of aerosol/meteorology relationships generally explains more variance than multiple linear regression.

Our original plan in this study was to use the CART results not only to gain a basic understanding of extinction/meteorological relationships, but also to define explicit meteorological classes at each site for the purpose of weather-normalizing historical visibility trends. We found evidence, however, of problems with over-fitting the data in some of the decision-trees (especially when B rather than $ln\,B$ was used as the dependent variable). These over-fit problems can lead to serious difficulties when attempting to normalize long-term visibility trends for meteorology (Trijonis et al. 1979;

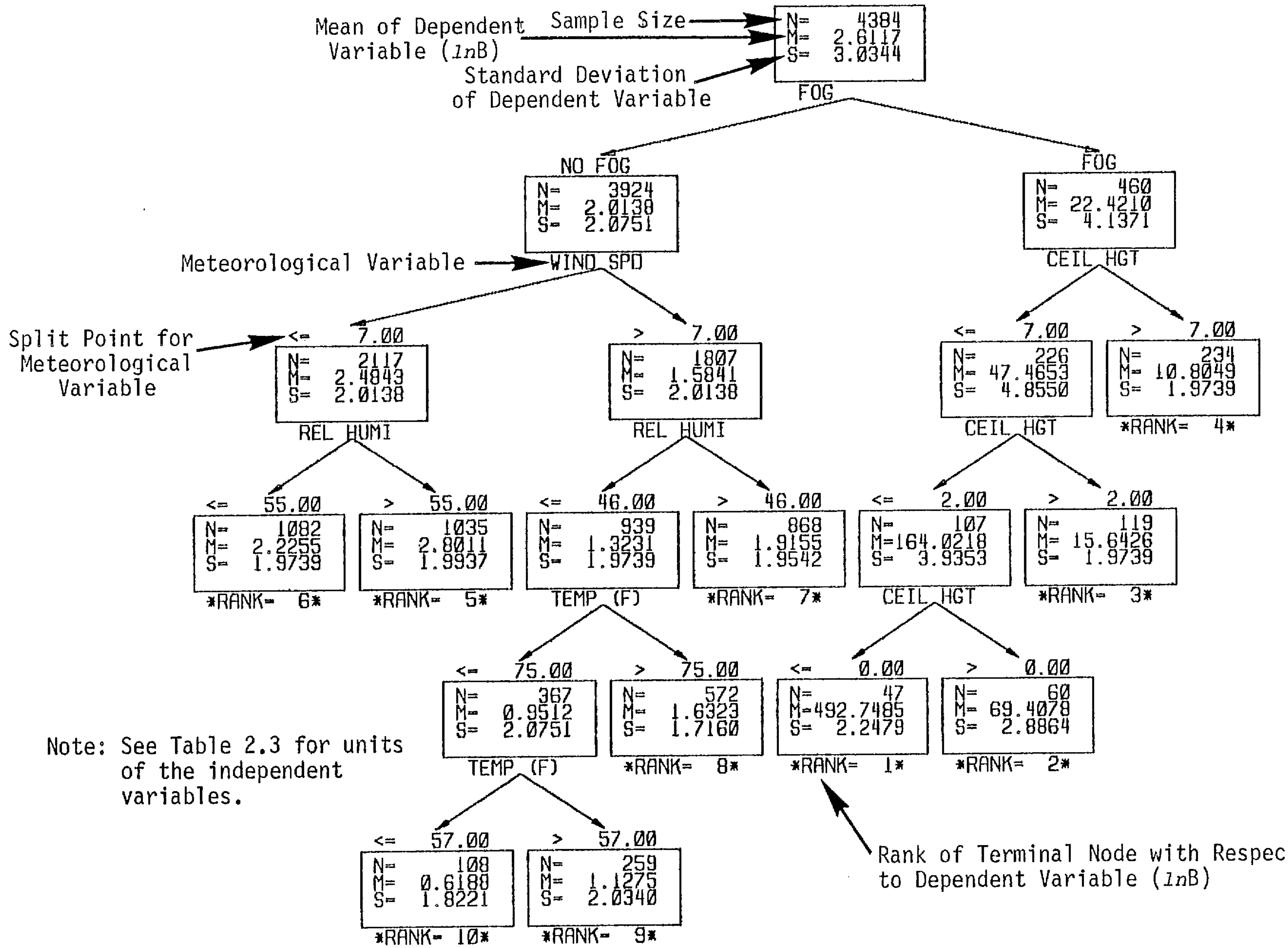

Figure 2.5 Example decision-tree, logarithim of extinction at Sacramento explained by meteorological variables.

Zeldin and Meisel 1978). Thus, we decided to use the CART trees only as a means of understanding the relationships between extinction and visibility. In the next section, general meteorological classes (applicable to all sites) are defined based on this understanding and on fundamental physical reasoning.

In order to illustrate the main features in the CART results, the decision-trees can be summarized as shown in Table 2.4. For each location, a "+" entry in the Table indicates a decision-tree split with a positive relationship between extinction and the meteorological variable. A "-" entry denotes a decision-tree split with a negative relationship between extinction and the meteorological variable. For example, the "+" entries for relative humidity in Table 2.4 represent decision-tree splits whereby higher extinction is associated with higher relative humidity. The circled values denote the first split in the tree, e.g. the split on FOG in Figure 2.5. As an aid in understanding the meaning of the Table, the reader can compare Figure 2.5 with the Sacramento results in Table 2.4b.

Table 2.4a presents the results for the case where extinction (B) is related to all 11 meteorological variables using all 4384 data points at each location. In this case, most of the decision-trees have a similar form; there is an initial split on fog, with the foggy days then split two or three times according to ceiling height (see, for example, Figure 2.6 for Medford). In order to best explain the variance in B, the decision-trees are focusing on the worst-case outliers (foggy days) and measuring the intensity of the fog according to ceiling height. The frequency of fog is typically from 5% to 15% at all sites except the two desert sites (where fog occurs less than 1% of the time) and Arcata (where fog occurs 25% of the time.

The one other interesting feature in Table 2.4a is the initial split on blowing dust at Yuma. Evidently, worst-case conditions at Yuma tend to be associated with the 1% of hours when blowing dust is recorded.* It should

*Actually, more than 1% of the hours at Yuma may have some degree of blowing dust, because blowing dust need only be recorded by the airport meteorologist if it restricts visibility to less than 7 miles.

TABLE 2.4 SUMMARY OF DECISION-TREE RELATIONSHIPS BETWEEN EXTINCTION AND METEOROLOGY, ALL DATA INCLUDED.

Table 2.4a Extinction versus meteorology.

LOCATION	WEATHER PARAMETER: FOG	REL HUMI	TEMP (F)	CEIL HGT	WIND SPD	SKY COVR	BLW DUST	LIQUD PR	FROZN PR	BLW SNOW	THUNDERS
<u>COASTAL - METROPOLITAN</u>											
San Francisco (Int.)	⊕			--							
Long Beach	⊕	++--		---		-+-					
San Bernardino	⊕			---							
San Diego (Int.)	+	⊕+	-+	-	-						
<u>COASTAL - RURAL</u>											
Arcata	⊕			---							
Santa Maria	⊕			--							
<u>NORTHERN VALLEY</u>											
Medford	⊕			---							
Red Bluff	⊕	+	+-++	--							
<u>CENTRAL VALLEY</u>											
Sacramento	⊕			---							
Fresno	⊕			---							
Bakersfield	⊕			--							
<u>DESERT</u>											
Bishop		+		⊖---							
Yuma	+	+-	-+		-+	+-	⊕				

Table 2.4b Log-extinction versus meteorology.

LOCATION	WEATHER PARAMETER: FOG	REL HUMI	TEMP (F)	CEIL HGT	WIND SPD	SKY COVR	BLW DUST	LIQUD PR	FROZN PR	BLW SNOW	THUNDERS
<u>COASTAL - METROPOLITAN</u>											
San Francisco (Int.)	+	⊕+++	++-	----	---						
Long Beach	+	⊕++	++	--	--						
San Bernardino	+	⊕+++	++++	----							
San Diego (Int.)	+	⊕+++		---+ ---							
<u>COASTAL - RURAL</u>											
Arcata	⊕			---- -							
Santa Maria	+++	++++	++	⊖---							
<u>NORTHERN VALLEY</u>											
Medford	+	⊕++		---							
Red Bluff	++	⊕++		---- --							
<u>CENTRAL VALLEY</u>											
Sacramento	⊕	++	++	---	-						
Fresno	⊕	+	-	---	-						
Bakersfield	+	⊕+		---	-						
<u>DESERT</u>											
Bishop		+		⊖---			+				
Yuma		+++	⊕++	---	++++		++++				

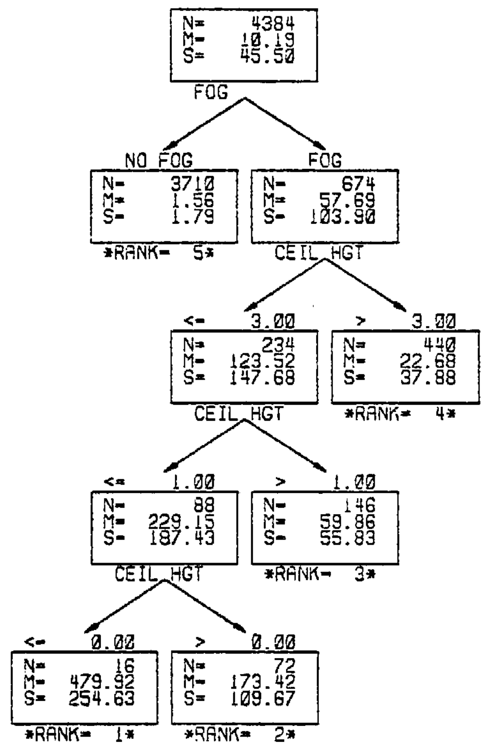

Figure 2.6 Decision-tree for Medford relating extinction to weather parameters.

be noted, however, that other studies (Trijonis 1979; Macias et al. 1979) have suggested that long-range transport of secondary aerosols (rather than blowing dust) tends to be the dominant contributor to visibility reduction in the desert Southwest on typical days (rather than worst-case days).

Table 2.4b presents the results when the dependent variable is *ln* B; the logarithim transformation places less weight on worst-case days. Most of the decision-trees still contain branches that are split on fog with further splits on ceiling height, but this aspect is no longer the overwhelming feature in the trees. Relative humidity and, to a lesser extent, temperature, emerge as important variables that are positively correlated with extinction. Relative humidity is a key variable because it relates to fog, precipitation, and the hygroscopic/deliquescent properties of certain aerosols. Temperature may represent photochemical aerosols or other seasonal phenomena. A negative correlation between wind speed and extinction appears at many of the urban sites along the coast and in the central valley region; this may reflect the importance of dispersion in lessening visibility impacts from anthropogenic sources. At Yuma, the importance of dust to worst-cast days is indicated by the split on blowing dust and by the positive correlations between extinction and wind speed.

Because sorting with respect to fog is likely to be an initial step in developing meteorological stratification schemes, it is interesting to examine the relationship between extinction and weather parameters for the remainder of hours (i.e. non-fog hours). Table 2.5 summarizes the decision-tree analysis when foggy hours are excluded form the data base. It can be seen that relative humidity tends to be the most important variable related to extinction but that temperature, ceiling height, and wind speed are also significant. As noted previously, relative humidity and temperature exhibit positive correlations with extinction, while ceiling height displays negative correlations. Wind speed relates negatively to extinction at urban locations but positively at the two desert sites. Precipitation is significant at a few locations, and blowing dust is an important variable at both desert sites.

TABLE 2.5 SUMMARY OF DECISION-TREE RELATIONSHIPS BETWEEN EXTINCTION AND METEOROLOGY, HOURS WITH FOG ARE EXCLUDED.

Table 2.5a Extinction versus meteorology.

LOCATION	WEATHER PARAMETER										
	FOG	REL HUMI	TEMP [F]	CEIL HGT	WIND SPD	SKY COVR	BLW DUST	LIQUD PR	FROZN PR	BLW SNOW	THUNDERS
COASTAL - METROPOLITAN											
San Francisco (Int.)		++		+	⊖-						
Long Beach		⊕+++	+	--	----						
San Bernardino		⊕+	++								
San Diego (Int.)		⊕++		+--+ -							
COASTAL - RURAL											
Arcata		+	--+	⊖---							
Santa Maria		⊕-+	++		-+						
NORTHERN VALLEY											
Medford		⊕+						-	++		
Red Bluff		⊕		---					+		
CENTRAL VALLEY											
Sacramento		+++	-		⊖			+			
Fresno		+-	⊖-		--						
Bakersfield		⊕									
DESERT											
Bishop			--	⊖---			+		+		
Yuma							+				

Table 2.5b Log-extinction versus meteorology.

LOCATION	WEATHER PARAMETER										
	FOG	REL HUMI	TEMP F	CEIL HGT	WIND SPD	SKY COVR	BLW DUST	LIQUD PR	FROZN PR	BLW SNOW	THUNDERS
COASTAL - METROPOLITAN											
San Francisco (Int.)		++++ ++++	++		⊖--						
Long Beach		⊕+++ ++	++++ +		--						
San Bernardino		⊕+++ ++++	++++ ++								
San Diego (Int.)		⊕+++	+	+--- +-							
COASTAL - RURAL											
Arcata		+++	+	⊖--				+			
Santa Maria		⊕+++	++++	---	-						
NORTHERN VALLEY											
Medford		⊕+++		-	-	++		-	+		
Red Bluff		⊕+++ +	+	--	-				+		
CENTRAL VALLEY											
Sacramento		+++	++		⊖						
Fresno		+++	-		⊖--						
Bakersfield		⊕+++		+--	--						
DESERT											
Bishop		++	-	⊖--- -	++++ ++++	-	++		+		
Yuma		++	⊕+++	---	++++		++++ +				

In order to gain further insights into extinction/meteorology relationships, it is useful to examine the intercorrelations among the important weather parameters (relative humidity, temperature, ceiling height, and wind speed). This will allow us to check the possibility that certain meteorological parameters are correlated with extinction only because they are correlated with other meteorological parameters which in turn affect extinction. Table 2.6 summarizes the intercorrelations among the weather parameters on days without fog or precipitation. The most striking feature of Table 2.6 is the high negative correlation between relative humidity and temperature. That relative humidity and temperature both relate positively with extinction despite their negative intercorrelation indicates that these two variables represent two distinct types of phenomenon affecting extinction. For example, relative humidity may reflect the amount of water that becomes attached to the aerosol, while temperature may reflect photochemical aerosol production. Another noteworthy aspect of Table 2.6 is the significant negative intercorrelation between ceiling height and relative humidity; part of the negative relationship that we found between ceiling height and extinction may be due to the intercorrelation of ceiling height and relative humidity.

2.3.2 Procedures for Meteorological Stratification

This section develops methods for meteorological stratification of the extinction (or visibility) data. The basic purposes of meteorological stratification are twofold: first, to reduce the stochastic fluctuations caused by meteorology in our analysis of long-term visibility trends (Chapter 7), and second, to help separate man-made visibility impacts from natural visibility impacts in our analyses of geographical, seasonal, and diurnal patterns (Chapters 3, 4, and 5). With respect to the second purpose, it should be noted that it is impossible to completely segregate man-made impacts from natural impacts through meteorological classification. This important caveat will be emphasized repeatedly in the present and subsequent chapters.

As a first step in meteorological classification, we decided to separate out, as Class I, weather observations indicating obvious influences from

TABLE 2.6 INTERCORRELATIONS AMONG RELATIVE HUMIDITY, TEMPERATURE, CEILING HEIGHT, AND WIND SPEED.

LOCATION	CORRELATION COEFFICIENTS					
	Relative Humidity versus Temperature	Relative Humidity versus Ceiling Height	Relative Humidity versus Wind Speed	Temperature versus Ceiling Height	Temperature versus Wind Speed	Ceiling Height versus Wind Speed
COASTAL-METROPOLITAN						
San Francisco (Int.)	-.52	-.37	-.20	.23	.26	.08
Long Beach	-.45	-.43	-.28	.20	.30	.17
San Bernardino	-.62	-.43	-.38	.31	.37	.12
San Diego (Int.)	-.13	-.43	-.07	.15	.37	.08
COASTAL-RURAL						
Arcata	-.23	-.24	-.29	.03*	.28	.14
Santa Maria	-.58	-.37	-.23	.16	.28	.19
NORTHERN VALLEY						
Medford	-.81	-.38	-.40	.35	.31	-.14
Red Bluff	-.75	-.40	-.19	.28	.04	-.06
CENTRAL VALLEY						
Sacramento	-.76	-.29	-.25	.25	.11	-.06
Fresno	-.83	-.32	-.20	.27	.17	-.10
Bakersfield	-.82	-.34	-.40	.27	.38	-.04
DESERT						
Bishop	-.75	-.22	-.21	.12	.11	-.07*
Yuma	-.44	-.24	-.17	.10	.09	-.01
AVERAGE	-.59	-.34	-.25	+.21	+.24	+.02

*All correlation coefficients except the two marked by asterisks are significant at a 99% confidence level.

natural causes. Class I includes occurrences of fog, liquid precipitation, and frozen precipitation, as well as observations of blowing dust, sand, snow, or spray. To further minimize influences from blowing dust, Class I also includes all hours with wind speed greater than 12 knots. As noted above, this classification does not really seperate man-made impacts from natural impacts. During hours not classified as Class 1, a considerable fraction of total extinction may still arise from natural aerosols such as dust particles, sea spray, water droplets, or certain organic aerosols. Conversely, during Class I hours, man-made impacts can be very significant. For example, some extreme sulfate episodes are known to occur in conditions labeled as "fog" (Cass 1977; Trijonis et al. 1975). Also, blowing dust may be partly related to anthropogenic activities. Despite these caveats, however, it seems worthwhile to separate out Class I as defined above.

The next step in our analysis was to stratify the remainder of the data (i.e. non-Class I hours) according to ranges of meteorological variables. The meteorological variables that we focused on were relative humidity and, to a lesser extent, temperature; ceiling height and wind speed were also considered in some of the sorting schemes. The meteorological stratification schemes were evaluated according to two performance indices: (1) the percent of variance explained in B and lnB by the stratification, and (2) the weighted average among classes of the standard deviation of B within each class. These performance indices were computed individually for each of the 13 locations. To summarize the results (as in Table 2.7) the performance indices were averaged over all 13 locations.

The selection of specific numerical values for relative humidity, temperature, etc. at which to split the data was based on three considerations: (1) the numerical values where splits commonly occurred in the CART decision-trees; (2) physical insights (e.g. the known relationship between relative humidity and light scattering for certain aerosols); and (3) the need to include a significant portion of the data in each meteorological class. In some cases, we tested for the optimal numerical split points by trial-and-error; these tests indicated that the performance of the stratification schemes was insensitive to reasonable choices of the numerical split points.

TABLE 2.7 PERFORMANCE OF VARIOUS METEOROLOGICAL CLASSIFICATION SCHEMES.

CLASSIFICATION SCHEME	13-SITE AVERAGE OF PERCENT VARIANCE EXPLAINED IN EXTINCTION (B)		13-SITE AVERAGE OF WEIGHTED MEANS AMONG CLASSES OF STANDARD DEVIATION OF B WITHIN CLASSES Absolute Standard Deviation/ (as Percent of Average B)	
	B	$\ln B$	All Classes	All Classes Except Class I
1 CLASS SCHEME				
• All data.	0.0%	0.0%	41.3/(547%)	
2 CLASS SCHEME				
• Class I and non-Class I.	77.5%	56.9%	22.4/(278%)	3.2/(135%)
3 CLASS SCHEMES				
• Class I with remainder of data divided into two classes based on a relative humidity split at 70%.	78.2%	69.5%	22.2/(276%)	3.0/(127%)
• Class I with remainder of data divided into two classes based on a temperature split at 65 degrees F.	78.5%	72.2%	22.1/(275%)	2.9/(123%)
4 CLASS SCHEME				
• Class I with remainder of data divided into three classes based on relative humidity splits at 40% and 70%.	78.4%	77.2%	21.8/(273%)	2.5/(109%)
5 CLASS SCHEMES				
• Class I with remainder of data divided into four classes based on relative humidity splits at 40%. 70%, and 80%.	78.4%	78.1%	21.8/(273%)	2.5/(108%)

TABLE 2.7 PERFORMANCE OF VARIOUS METOEROLOGICAL CLASSIFICATION SCHEMES. (Continued)

CLASSIFICATION SCHEME	13-SITE AVERAGE OF PERCENT VARIANCE EXPLAINED IN EXTINCTION (B)		13-SITE AVERAGE OF WEIGHTED MEAN AMONG CLASSES OF STANDARD DEVIATION OF B WITHIN CLASSES — Absolute Standard Deviation/(as Percent of Average B)	
	B	*ln*B	All Classes	All Classes Except Class I
• Class I with remainder of data divided into four classes based on temperature splits at 50, 65, and 80 degrees F.	78.6%	78.2%	21.8/(273%)	2.5/(108%)
6 CLASS SCHEME				
• Class I with remainder of data divided into five classes based on relative humidity splits at 35%, 55%, 70%, and 80%.	78.7%	81.0%	21.6/(271%)	2.3/(99%)
7 CLASS SCHEMES				
• Class I with remainder of data divided into six classes based on relative humidity splits at 25%, 45%, 60%, 70%, and 80%.	78.8%	82.4%	21.6/(270%)	2.2/(96%)
• Class I with remainder of data divided into six classes based on a matrix of relative humidity splits at 40% and 70%, and a temperature split at 65 degrees F.	78.8%	81.5%	21.6/(272%)	2.3/(98%)
8 CLASS SCHEMES				
• Class I with remainder of data divided into seven classes based on relative humidity splits at 20%, 35%, 50%, 60%, 70%, and 80%.	78.9%	83.3%	21.6/(271%)	2.2/(96%)

TABLE 2.7 PERFORMANCE OF VARIOUS METEOROLOGICAL CLASSIFICATION SCHEMES. (Continued)

CLASSIFICATION SCHEME	13-SITE AVERAGE OF PERCENT VARIANCE EXPLAINED IN EXTINCTION (B)		13-SITE AVERAGE OF WEIGHTED MEAN AMONG CLASSES OF STANDARD DEVIATION OF B WITHIN CLASSES: Absolute Standard Deviation/ (as Percent of Average B)	
	B	$\ln B$	All Classes	All Classes Except Class I
• Class I; a class eliminating data with temperature below 50 degrees F or above 80 degrees F; with remainder of data divided into six classes based on relative humidity splits at 25%, 45%, 60%, 70%, and 80%.	78.9%	82.4%	21.6/(271%)	2.3/(96%)
• Class I; a class eliminating data with ceiling height below 4,000 feet; with remainder of data divided into six classes based on relative humidity splits at 25%, 45%, 60%, 70%, and 80%.	78.9%	82.9%	21.6/(270%)	2.1/(97%)
• Class I; a class eliminating data with temperature below 50 degrees F or above 85 degrees F and/or ceiling height below 4,000 feet; with remainder of data divided into six classes based on relative humidity splits at 25%, 45%, 60%, 70%, and 80%.	78.9%	81.6%	21.6/(270%)	2.2/(100%)
• Class I; a class eliminating data with ceiling height below 4,000 feet; with remainder of data divided into six classes based on a matrix of relative humidity splits at 40% and 70% and a temperature split at 65 degrees F.	78.8%	82.2%	21.6/(271%)	2.2/(100%)

TABLE 2.7 PERFORMANCE OF VARIOUS METEOROLOGICAL CLASSIFICATION SCHEMES. (Continued)

CLASSIFICATION SCHEME	13-SITE AVERAGE OF PERCENT VARIANCE EXPLAINED IN EXTINCTION (B)		13-SITE AVERAGE OF WEIGHTED MEAN AMONG CLASSES OF STANDARD DEVIATION OF B WITHIN CLASSES — Absolute Standard Deviation/ (as Percent of Average B)	
	B	$ln B$	All Classes	All Classes Except Class I
• Class I; a class eliminating data with ceiling height less than 4,000 feet and/or wind speeds below 2.5 knots or above 7 knots; with remainder of data divided into six classes based on a matrix of relative humidity splits at 40% and 70%, and a temperature split at 65 degrees F.	78.9%	80.1%	21.7/(272%)	2.4/(106%)

Table 2.7 summarizes the performance of several meteorological classification schemes. One significant feature in Table 2.7 is that sorting by relative humidity yields about the same performance as sorting by temperature (see the results for the two 3-class schemes and the two 5-class schemes). Given that relative humidity and temperature perform about equally in explaining the variance in extinction, there are other reasons to prefer the use of relative humidity rather than temperature as the sorting variable. The major reason is that relative humidity bears a fairly well understood physical relationship to extinction (via the hygroscopic and/or deliquescent properties of certain aerosols). The physical link between temperature and extinction, however, is not so obvious; temperature may just be a surrogate for photochemical aerosol production or other seasonal factors. Relative humidity also is preferable because it bears a consistent (positive) relationship to extinction at all the sites (see Table 2.5b). Temperature usually shows a positive correlation with extinction but sometimes exhibits a negative correlation (e.g. at Fresno and Bishop). Finally, sorting by temperature might defeat some of the purpose of our meteorological stratification schemes. Specifically, if higher temperature reflects more anthropogenic photochemical aerosols in certain seasons or at certain locations, we want this man-made impact to appear in -- not to be eliminated in -- the weather sorted data.

A second notable feature in Table 2.7 is that, for a given number of classes, sorting by relative humidity alone performs as well as sorting jointly by relative humidity, temperature, ceiling height, and/or wind speed (see the 7-class and 8-class schemes in Table 2.7). Based on this observation and the discussion of the previous paragraph, it appears justifiable to stratify the data only by relative humidity classes (in addition to Class I).

There is an obvious trade-off in choosing the number of meteorological classes: a greater number of classes explains more of the variance in extinction, but a lesser number of classes decreases the complexity and leaves more data points in each class. To better understand this trade-off, we have plotted the percent variance explained in B and lnB as a function of the number of meteorological classes (see Figure 2.7). The percent variance explained in B obviously reaches diminishing returns after two relative humidity classes, e.g. a relative humidity split at 70%. The percent variance explained in $\ln B$ seems to reach diminishing returns after three relative humidity classes, e.g. relative humidity splits at 40% and 70%. For use in this report, we have chosen the stratification scheme involving three relative humidity classes in addition to Class I. Specifically, the 4-class meteorological stratification that we will use is as follows:

Class I: fog, precipitation, blowing dust/snow, or wind speed > 12 knots.

Class II: non-Class I and relative humidity < 40%.

Class III: non-Class I and 40% ≤ relative humidity < 70%.

Class IV: non-Class I and 70% ≤ relative humidity.

For the 4-class meteorological stratification scheme at the 13 test sites, Table 2.8 summarizes the percent variance explained in extinction and the distribution of hours among classes. It can be seen that the percent variance explained in extinction by the meteorological sorts ranges from approximately 61% to 90% and averages about 78% among the 13 sites. These percents of variance explained are equivalent to correlation coefficients between extinction and meteorology ranging from about 0.78 to 0.95 and averaging 0.88. As noted earlier in Section 2.1.2, such high correlation coefficients reflect the consistency of the airport visibility data.

As indicated by the bottom right side of Table 2.8, the distribution of hours among classes is fairly uniform considering all the sites together. Considering individual sites, however, there are sometimes very few data points in certain classes (e.g. few Class IV hours at the desert sites, or few Class II hours at some of the coastal sites). We found that the problem of insufficient data points in certain meteorological classes becomes very critical when one examines not only individual locations, but also individual seasons or times of day. Because of this problem, we usually will use (in later chapters) only Class III -- which always has enough data

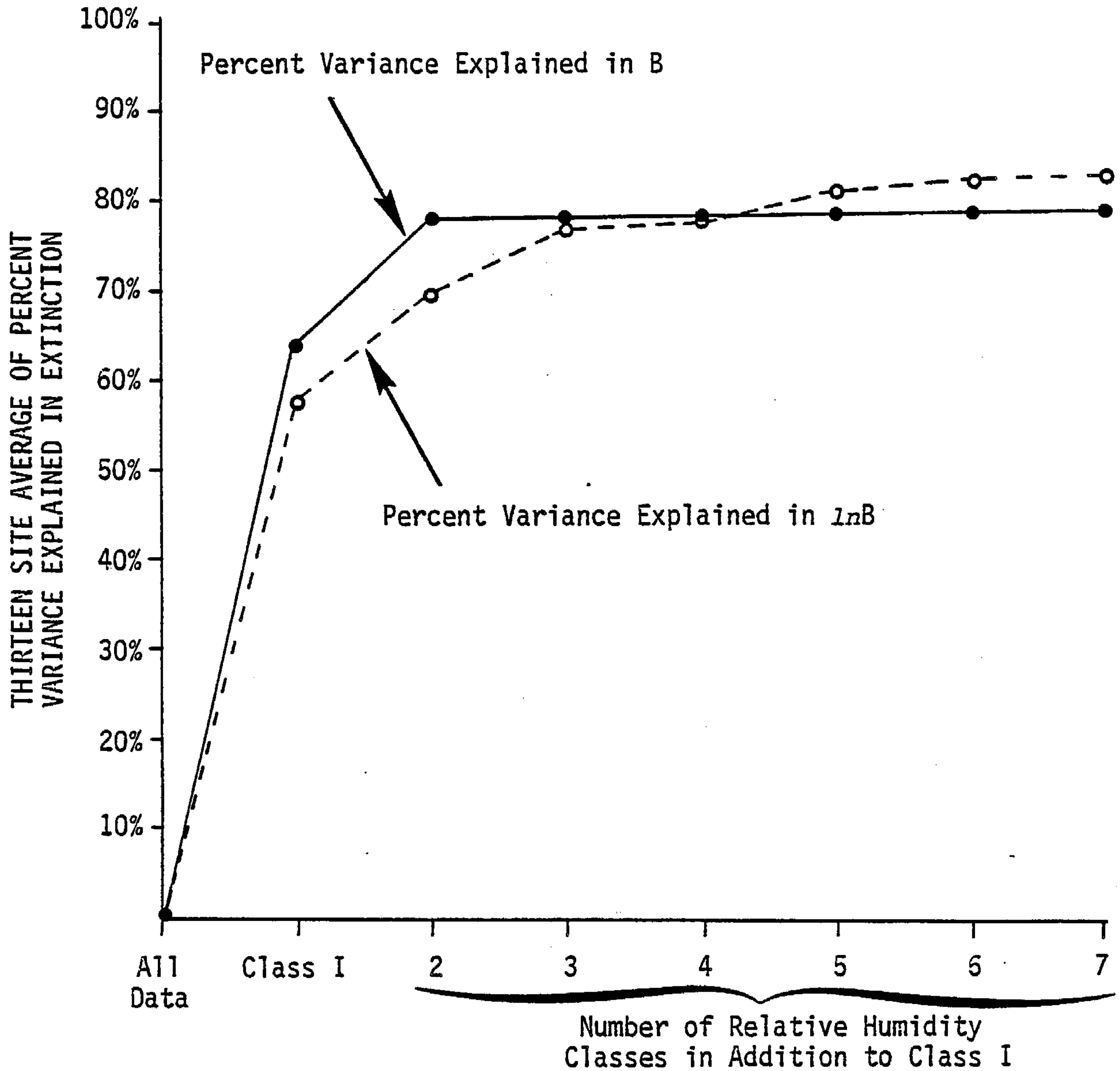

Figure 2.7 Percent variance explained in extinction as a function of the number of meteorological classes.

TABLE 2.8 SUMMARY OF THE 4-CLASS METEOROLOGICAL SCHEME* APPLIED TO THE 13 TEST LOCATIONS.

LOCATION	PERCENT VARIANCE EXPLAINED BY THE METEOROLOGICAL STRATIFICATION		DISTRIBUTION OF DAYTIME HOURS† BY METEOROLOGICAL CLASS			
	in B	in lnB	Class I	Class II	Class III	Class IV
COASTAL-METROPOLITAN						
San Francisco (Int.)	61.2%	68.2%	39.0%	4.2%	27.5%	29.3%
Long Beach	90.0%	77.5%	10.6%	12.9%	50.4%	26.1%
San Bernardino	86.2%	77.8%	14.3%	38.2%	33.2%	14.3%
San Diego (Int.)	88.3%	76.2%	11.7%	10.9%	52.9%	24.5%
COASTAL-RURAL						
Arcata	61.3%	71.2%	41.0%	1.0%	13.7%	44.3%
Santa Maria	68.2%	73.4%	32.5%	8.6%	34.2%	24.7%
NORTHERN VALLEY						
Medford	77.6%	87.2%	25.2%	21.9%	31.7%	21.2%
Red Bluff	74.5%	78.3%	26.2%	34.9%	25.3%	13.6%
CENTRAL VALLEY						
Sacramento	75.8%	76.6%	25.4%	23.3%	33.1%	18.2%
Fresno	87.3%	86.0%	14.3%	30.6%	36.8%	18.3%
Bakersfield	88.7%	80.6%	12.1%	37.0%	38.3%	12.6%
DESERT						
Bishop	75.2%	77.8%	24.9%	53.5%	15.9%	5.7%
Yuma	85.2%	72.2%	14.9%	62.9%	18.2%	4.0%
AVERAGE	78.4%	77.2%	22.5%	26.1%	31.6%	19.8%

*See the text for a description of the 4-Class meteorological scheme.

†Based on three years of data for the 7:00 AM, 10:00 AM, 1:00 PM, and 4:00 PM PST observations.

points -- when comparing meteorologically stratified visibility levels among various locations, seasons, or times of day.

Although the above meteorological classification scheme was developed and tested using data for only 13 locations, it will be applied in subsequent chapters to a total of 24 locations for which we have computerized records. The applications will include meteorological adjustment of geopraphical visibility patterns (Chapter 3), seasonal visibility variations (Chapter 4), diurnal visibility patterns (Chapter 5), and long-term visibility trends (Chapter 7).

3.0 GEOGRAPHICAL PATTERNS OF VISIBILITY

The spatial gradients of visibility in California are far more severe and complex than those observed anywhere else in the United States (Trijonis and Shapland 1979). Parts of California (e.g. along the Nevada border) exhibit among the best visibilities in the nation, while other parts (e.g. within the Los Angeles basin) experience among the worst visibilities in the nation. The purpose of this chapter is to characterize these complex spatial patterns of visibility.

3.1 ISOPLETH MAP OF MEDIAN VISIBILITIES

This section develops an isopleth map of existing visibility levels in California. The map is based on median 1:00 PM visibilities for the years 1974-1976 at 67 locations. The locations and altitudes of the 67 study sites are illustrated in Figures 2.1 and 2.3 of Section 2.1.1.

The visibilities reported in this section are based on all observations, with no sorting for meteorology. We are thus characterizing the entire statistical distribution of 1:00 PM visibilities experienced at each location. The spatial patterns that we observe are due to both climatological variations and air quality variations. Later, in Section 3.3, to achieve a better understanding of man-made impacts on the spatial patterns of visibility, we will stratify the visibility data for some of the sites according to meteorology.

3.1.1 Determination of Median Visibilities

Median visibilities at the 67 study locations are determined using the procedures outlined in Section 2.2 and the cumulative frequency distributions presented in Appendix C. Table 3.1 lists the 65 study locations and the median 1:00 PM visibilities for 1974-1976. Special remarks are made to note locations which involve extrapolation of the frequency distribution or which have limited data availability. Asterisks placed on some of the median visibilities denote those that are based on uncertain extrapolation of the cumulative frequency distribution.

TABLE 3.1 LIST OF STUDY SITES AND MEDIAN 1:00 PM VISIBILITIES FOR 1974 - 1976.

AIR BASIN, Site	Median 1:00 PM Visibilities (miles)	REMARKS
NORTH COAST		
Arcata	15	
Crescent City	23	
Ukiah	31	Based on 1974 data only. No data are available for 1976 and reporting practices change in the middle of 1975.
SACRAMENTO VALLEY		
Marysville	38	
Red Bluff	61	
Sacramento	14	
NORTHEAST PLATEAU AND SOUTHERN OREGON		
Burns	65	Based on linear extrapolation of frequency distribution
Lakeview	50*	Based on uncertain nonlinear extrapolation of frequency distribution. Data available only for 1974.
Medford	25	
Montague	47	Reporting practices change in 1975. Linear extrapolation of 1974 distribution yields a 46 mile median; interpolation of 1976 distribution yields a 47 mile median.
Susanville	64	Based on linear extrapolation of frequency distribution. Data available only for 1975.
MOUNTAIN COUNTIES AND LAKE TAHOE		
Blue Canyon	46	
South Lake Tahoe	50*	Based on uncertain nonlinear extrapolation of frequency distribution. Data available only for 1974 and 1975.

TABLE 3.1 LIST OF STUDY SITES AND MEDIAN 1:00 PM VISIBILITIES FOR 1974 - 1976, Continued.

AIR BASIN, Site	Median 1:00 PM Visibilities (miles)	REMARKS
SAN FRANCISCO BAY AREA		
Concord	24	
Fairfield	21	Data available only for 1974 and 1975.
Hayward	18	
Napa	24	
Oakland	14	
Pillar Point	7	Data available only for 1974 and 1975.
San Francisco Int.	15	
San Francisco PBS	8	Data available only for 1974.
San Jose	16	
Santa Rosa	28	Based on 1974 and 1975 data only. Reporting practices change in 1976.
Sunnyvale	10	Data available only for 1974 and 1975.
NORTH CENTRAL COAST		
Monterey	15	
Salinas	21	
SAN JOAQUIN VALLEY		
Bakersfield	14	
Fresno	13	
Lemoore	13	Data available only for 1974 and 1975.
Merced	13	
Modesto	21	
Stockton	18	
Visalia	9	
GREAT BASIN VALLEYS AND WESTERN NEVADA		
Bishop	90*	Based on uncertain nonlinear extrapolation of the frequency distribution.
Tonopah	90*	Based on uncertain nonlinear extrapolation of the frequency distribution.

TABLE 3.1 LIST OF STUDY SITES AND MEDIAN 1:00 PM VISIBILITIES FOR 1974 - 1976, Continued.

AIR BASIN, Site	Median 1:00 PM Visibilities (miles)	REMARKS
SOUTH CENTRAL COAST		
Oxnard	13	
Paso Robles	32	
San Luis Obispo	14	Reporting practices change in 1975. Non-linear extrapolation of 1974-1975 data (last 2 quarters of 1974, 1st 2 quarters of 1975) yields a 15 mile median. Interpolation of 1976 distribution yields a 13 mile median.
Santa Barbara	12	
Santa Maria	22	
SOUTH COAST (Coastal Part)		
Fullerton	8	
Long Beach	11	
Newport Beach	12	Data available only for 1976.
San Nicolas	12	
Santa Catalina	22	Data available only for July 1974 - June 1976.
Santa Monica	11	
SOUTH COAST (Inland Part)		
Burbank	9	Based on 1974 and 1975 data only. Reporting practices change during 1976.
El Monte	8	
Ontario	7	
San Bernardino	9	Data available only for 1974 and 1975; reporting practices change at the end of 1974. Interpolation of 1974 and 1975 frequency distributions both yield 9 mile medians.

TABLE 3.1 LIST OF STUDY SITES AND MEDIAN 1:00 PM VISIBILITIES FOR 1974 - 1976, Continued.

AIR BASIN, Site	Median 1:00 PM Visibilities (miles)	REMARKS
Sandberg	49	
SE Riverside	13	Based on 1974 data only. No data are available for 1976 and reporting practices change in the middle of 1975.
SAN DIEGO		
Campo	60*	Based on uncertain nonlinear extrapolation of frequency distribution.
Camp Pendleton	12	Data available only for 1974.
Carlsbad	16	Data available only for 1974 and 1975.
NE San Diego	18	
San Diego	13	Reporting practices change in 1975. Interpolation of 1974 distribution yields a 13 mile median; interpolation of 1976 distribution yields a 14 mile median.
S San Diego	14	
SOUTHEAST DESERT AND WESTERN ARIZONA		
Barstow	36	Reporting practices change at the end of 1975. Interpolation of 1974-1975 distribution yields a 35 mile median; nonlinear extrapolation of the 1976 distribution yields a 38 mile median.
Blythe	60*	Based on uncertain nonlinear extrapolation of the frequency distribution.
China Lake	60*	Reporting procedures change in 1974 and 1975. Uncertain nonlinear extrapolation of the 1976 distribution yields a 65-70 mile median. Nephelometry data for 1975 and 1976 provided by Tom Dodson of the Naval Weapons Center indicates a 50 mile median.
Imperial	31	

TABLE 3.1 LIST OF STUDY SITES AND MEDIAN 1:00 PM VISIBILITIES FOR 1974 - 1976, Continued.

AIR BASIN, Site	Median 1:00 PM Visibilities (miles)	REMARKS
Lancaster	30	Based on 1975 and 1976 data only. Reporting practices change during 1974.
Needles	50	Based on nonlinear extrapolation of cumulative frequency distribution.
Palm Springs	24	
Victorville	33	Based on 1974 data only. Reporting change occurs in 1975 and no data are available for 1976.
Yuma	59	

* = based on uncertain nonlinear extrapolation of frequency distribution

The remarks in Table 3.1 also note those locations which changed reporting practices during 1974-1976. In determining cumulative frequency distributions, it is important not to mix two data sets involving different reporting procedures. The year during which reporting practices changed is eliminated from the analysis, and an overall median visibility is determined by averaging the medians for the other two years.

3.1.2 Preparation of an Isopleth Map

Figure 3.1 presents median 1:00 PM visibilities plotted at the locations of the 67 study sites. The generally good quality of the visibility data is evidenced in Figure 3.1 by the monotonic gradients that often exist in passing from areas of poor visibility to areas of good visibility, and by the consistency of the readings at many neighboring stations. As prime examples of monotonic spatial gradients, we note the following: on a straight line from Oxnard to Ontario, one encounters a sequence of data points of 13 miles, 9 miles, 8 miles, and 7 miles; continuing on another straight line from Ontario to Blythe, the sequence of data points proceeds as 7 miles, 13 miles, 24 miles, and 60 miles. As examples of consistency, we note that the five sites in the central part of the South Coast Air Basin (Burbank, El Monte, Fullerton, Ontario, and San Bernardino) all record visibilities of 7 to 9 miles, and that the seven sites in-and-near northeastern California (Montague, Red Bluff, Blue Canyon, South Lake Tahoe, Susanville, Lakeview, and Burns) all record visibilities of 46 to 65 miles.

The construction of a manually-drawn visibility isopleth map for California was essentially based on the data in Figure 3.1, but there were some other minor considerations. Firstly, in drawing isopleths near the Oregon, Nevada, and Arizona borders, we were guided by the results of our nationwide study of suburban/nonurban visibility (see Figures 3.2 and 3.3). In fact, isopleth values of 10, 15, 25, 45, and 70 miles were selected as a basis for the California map in order to facilitate comparison with the national map. Secondly, we considered the general topography of California (see Figure 3.4) when drawing the visibility isopleths; in several instances (e.g. along the coastline, around the San Joaquin Valley, and around the mountains east of

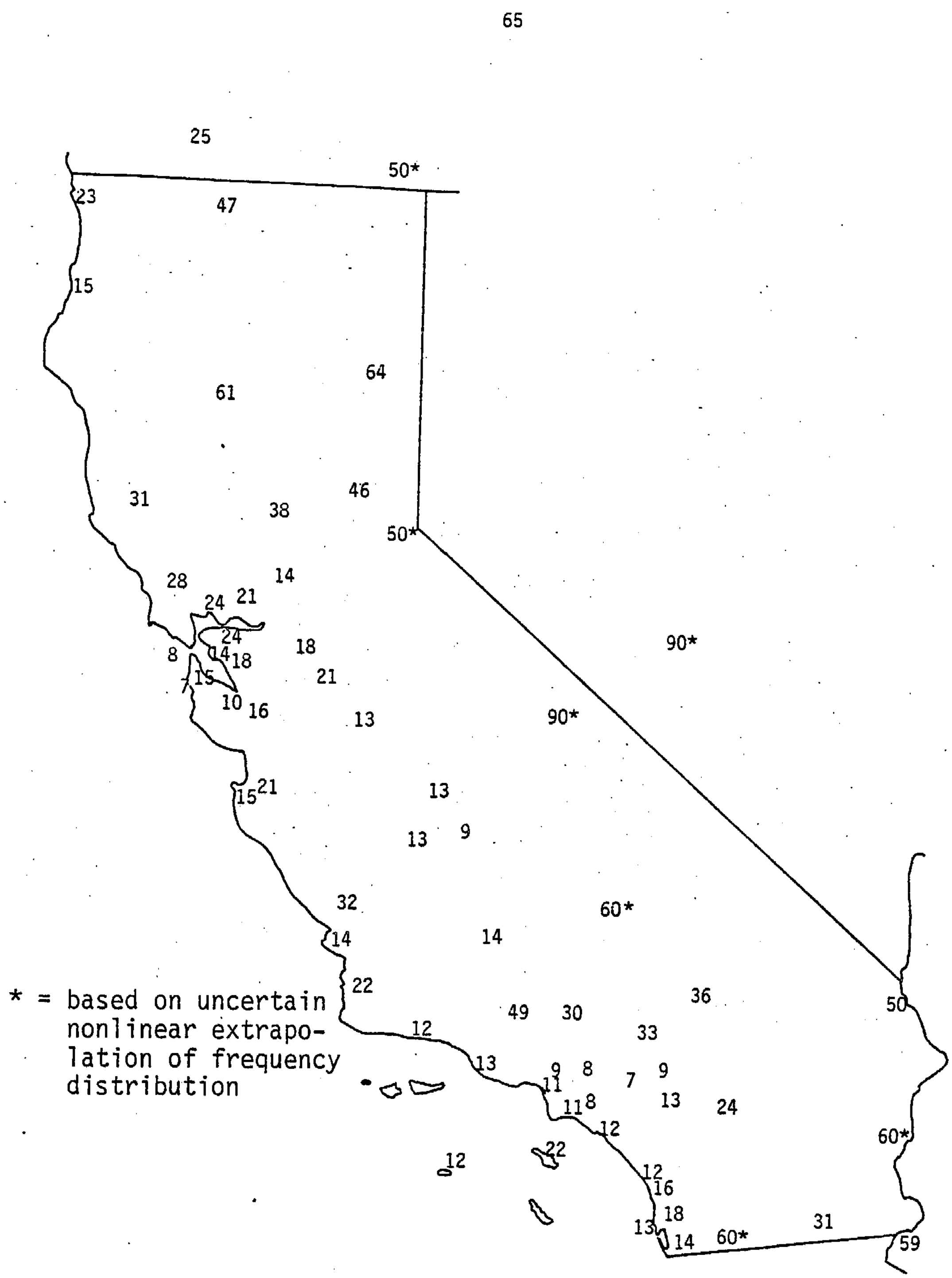

Figure 3.1 Median 1 PM visibilities (in miles) in California, 1974-1976.

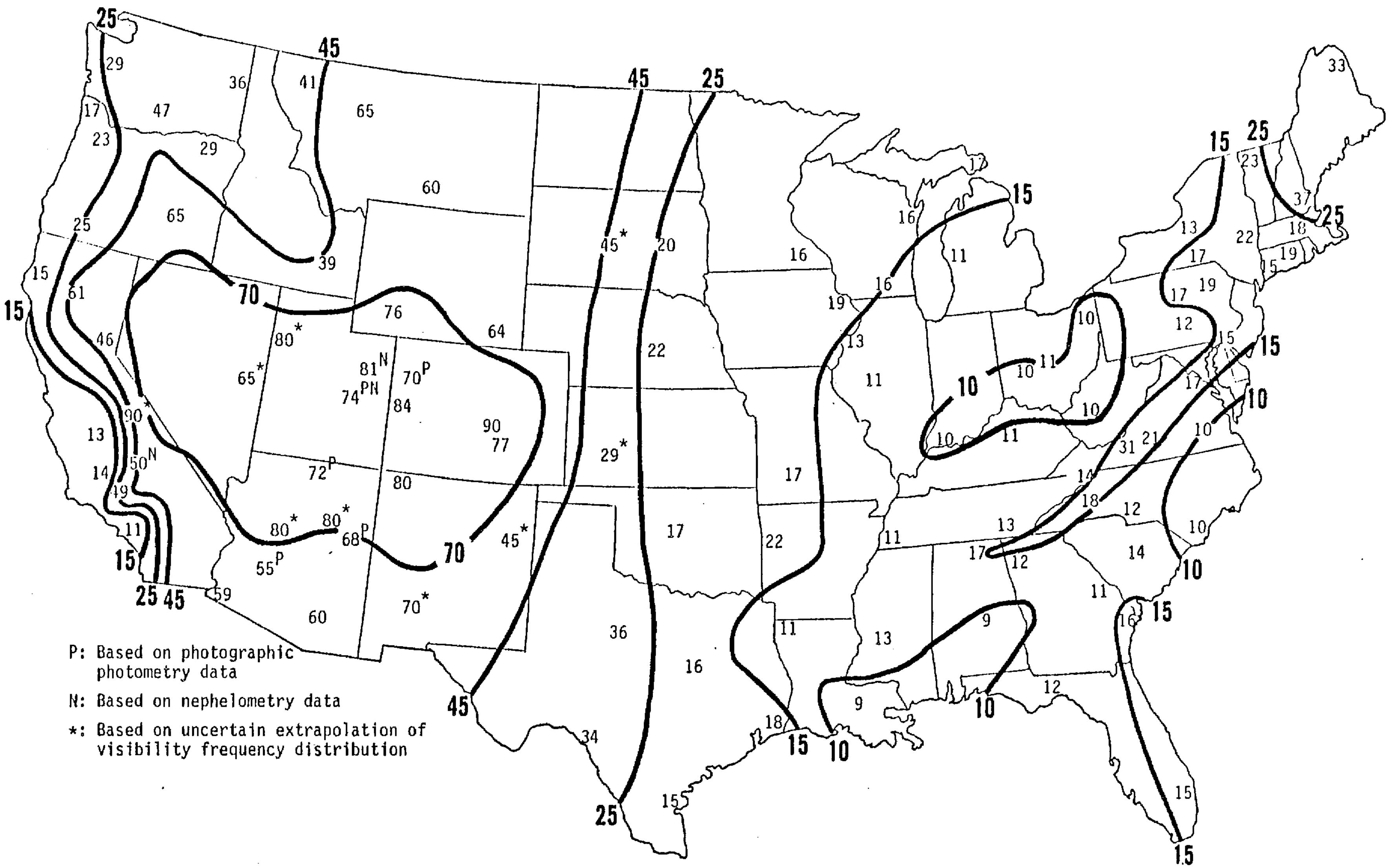

Figure 3.2 Median mid-day visibilities (in miles) and visibility isopleths for suburban/nonurban areas in the United States (Trijonis and Shapland, 1979).

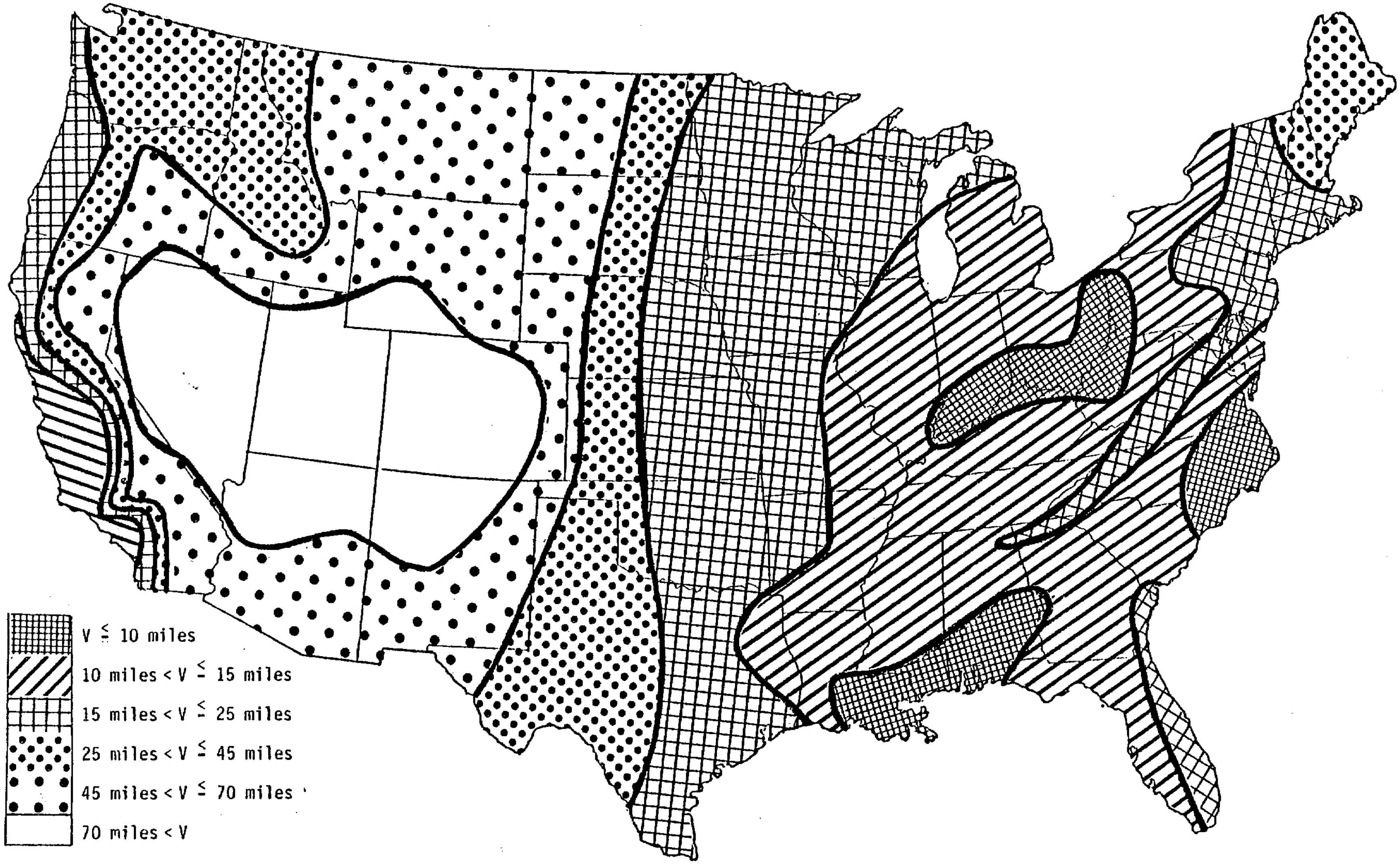

Figure 3.3 Shaded isopleth map of median mid-day visibilities for suburban/nonurban areas in the United States (Trijonis and Shapland, 1979).

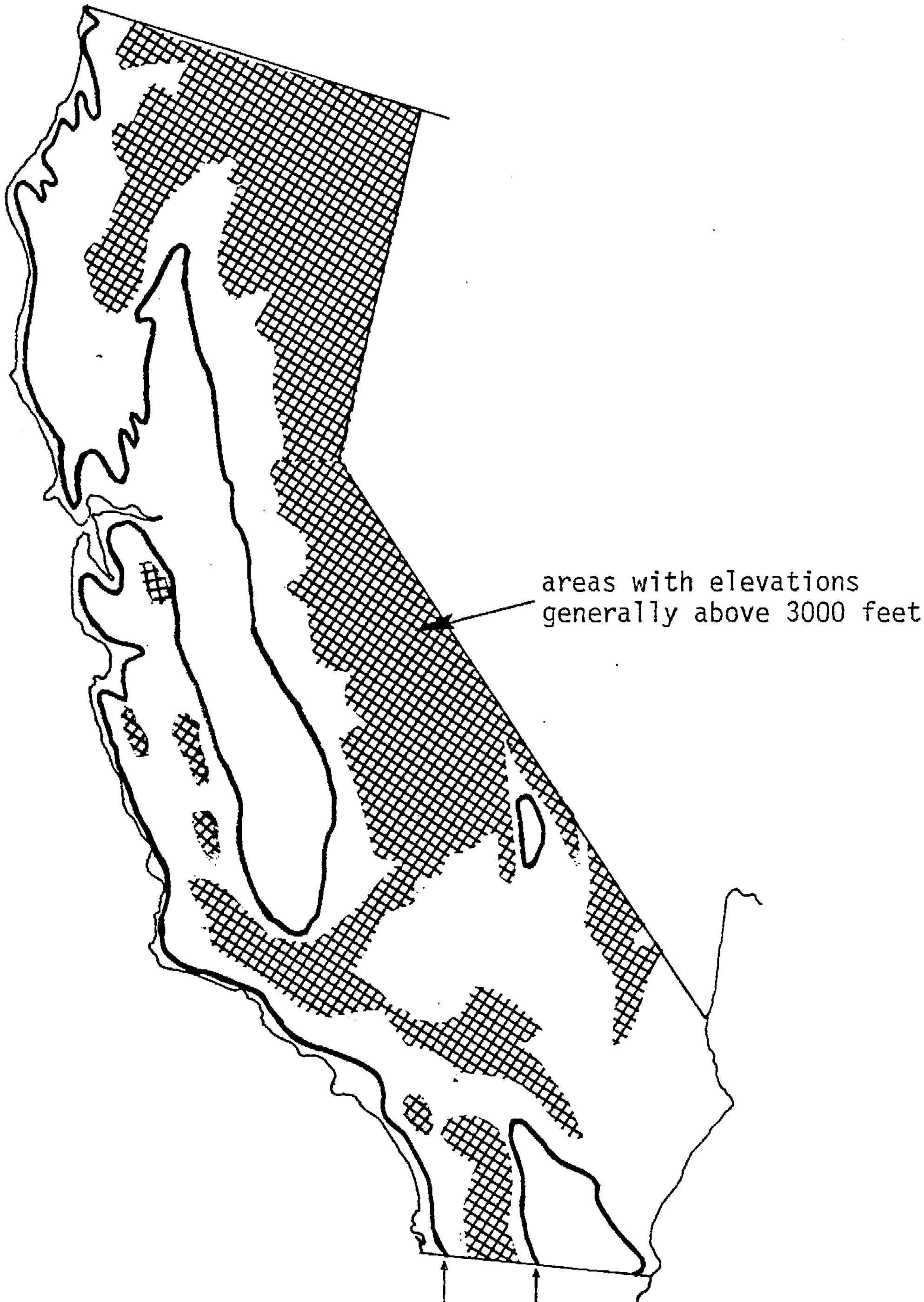

Figure 3.4 Topography of California.

San Diego) it made sense to have the isopleths correspond to major topographical features. Thirdly, we considered the potential imprecision of the median visibilities (seemingly on the order of 10 to 15% based on comparisons of nearby locations) and generally drew smooth isopleths rather than making tiny wiggles which might just represent errors in the data. Finally, we decided the following with respect to six locations where visibility seemed anomalous when compared to nearby sites:

- Santa Catalina airport exhibits a median visibility of 22 miles, well above the 11-13 medians found at 8 other coastal locations (including San Nicolas Island) in Southern California. The obvious reason for this is that the Santa Catalina station is atop a mountain at over 1500 feet elevation (see Figure 2.3). The much greater elevation at Santa Catalina compared to the other coastal locations evidently leads to lesser influence from low lying coastal fogs. We decided to ignore the Santa Catalina datum in constructing the isopleth map, i.e. we did <u>not</u> draw a special 15^+ isopleth to represent the very localized condition at that mountaintop.

- The Sandberg station, sited atop Bald Mountain in Southern California, yields a median visibility of 49 miles, well above the median visibilities at nearby locations. The reason for this anomaly again appears to be altitude; Sandberg is at an elevation of 4523 feet, much higher than nearby locations (see Figure 2.3). We decided <u>not</u> to draw a special 45^+ mile isopleth to represent the apparently localized condition at Sandberg.

- Visalia yields a median visibility of 9 miles, significantly below the 13-14 mile medians found at the 4 other locations in the central/southern San Joaquin Valley. Discussions with the weather observer at the Visalia airport verify that the low median visibility computed there is not due to any irregularities in reporting practices and indicate that the reason might be a greater frequency of stagnant air around Visalia. Nevertheless, we decided <u>not</u> to draw a special 10^- mile isopleth based on data solely from that one weather station.

- The data for Campo in southeastern San Diego County apparently imply a median visibility on the order of 60 miles. This is well above the median visibilities at nearby locations. We decided that the Campo data probably represented a real effect due to the generally higher terrain in that area and drew a 45^+ mile isopleth around the Vallecito Mountain Range.

- Two coastal locations near San Francisco, Pillar Point and San Francisco Pilot Boat, both yield very low median visibilities, 7 and 8 miles respectively. These values are significantly lower than the 11-15 mile visibilities typically found at most coastal sites in California. Because there are <u>two</u> sites verifying this low visibility, however, we decided to draw a 10^- mile isopleth around them.

- Sacramento exhibits a median visibility of 14 miles, significantly below the median visibilities at nearby locations. Because this perturbation might very well represent the effect of urban activities and agriculture in that area, we decided to draw a 15 mile isopleth surrounding the Sacramento metropolitan region.

Based on the above considerations, Figure 3.5 illustrates isopleths drawn to the California visibility data. Figure 3.6 presents a shaded isopleth map indicating regions where median visibility is in specified ranges.

3.1.3 Description of Spatial Visibility Patterns

Figures 3.5 and 3.6 indicate that the best visibility in California occurs along the Nevada border. One area along the border, Death Valley National Monument and the mountainous areas immediately northwest, experiences a median visibility of 70^+ miles. This area is on the fringe of a large region in the mountainous Southwest (basically consisting of Nevada, Utah, Colorado, northern Arizona, and northern New Mexico) which exhibits the highest visibilities found in the continental United States (see Figures 3.2 and 3.3).

Median visibility is also quite good, 45 - 70 miles, in the plateaus and mountains of northern California, the mountains of central-eastern California, the desert near the Arizona border, and the Vallecito Mountains east of San Diego. To the west of all these areas, very sharp gradients occur, with visibility falling to less than 15 miles along the entire California coastline except the far northern coast near Oregon, where visibility falls to less than 25 miles.

Two significant pockets of poor visibility occur between the coast and eastern California. Median visibility is less than 10 miles in the center of the South Coast Air Basin (including the area around Downtown Los Angeles; the San Fernando, San Gabriel, and Pomona Valleys; and the areas to the south and east through Anaheim, Riverside, and San Bernardino). Visibility is less than 15 miles in the large area covered by the central/southern San Joaquin Valley, from Merced to Bakersfield.

3.1.4 Comparison with Air Quality and Emission Patterns

It is interesting to compare the spatial patterns of visibility with the spatial patterns of ambient air pollutants and anthropogenic emissions that are known to cause visibility impairment. As discussed in Section 1.1, extinction from particles (aerosols) is the dominant factor controlling

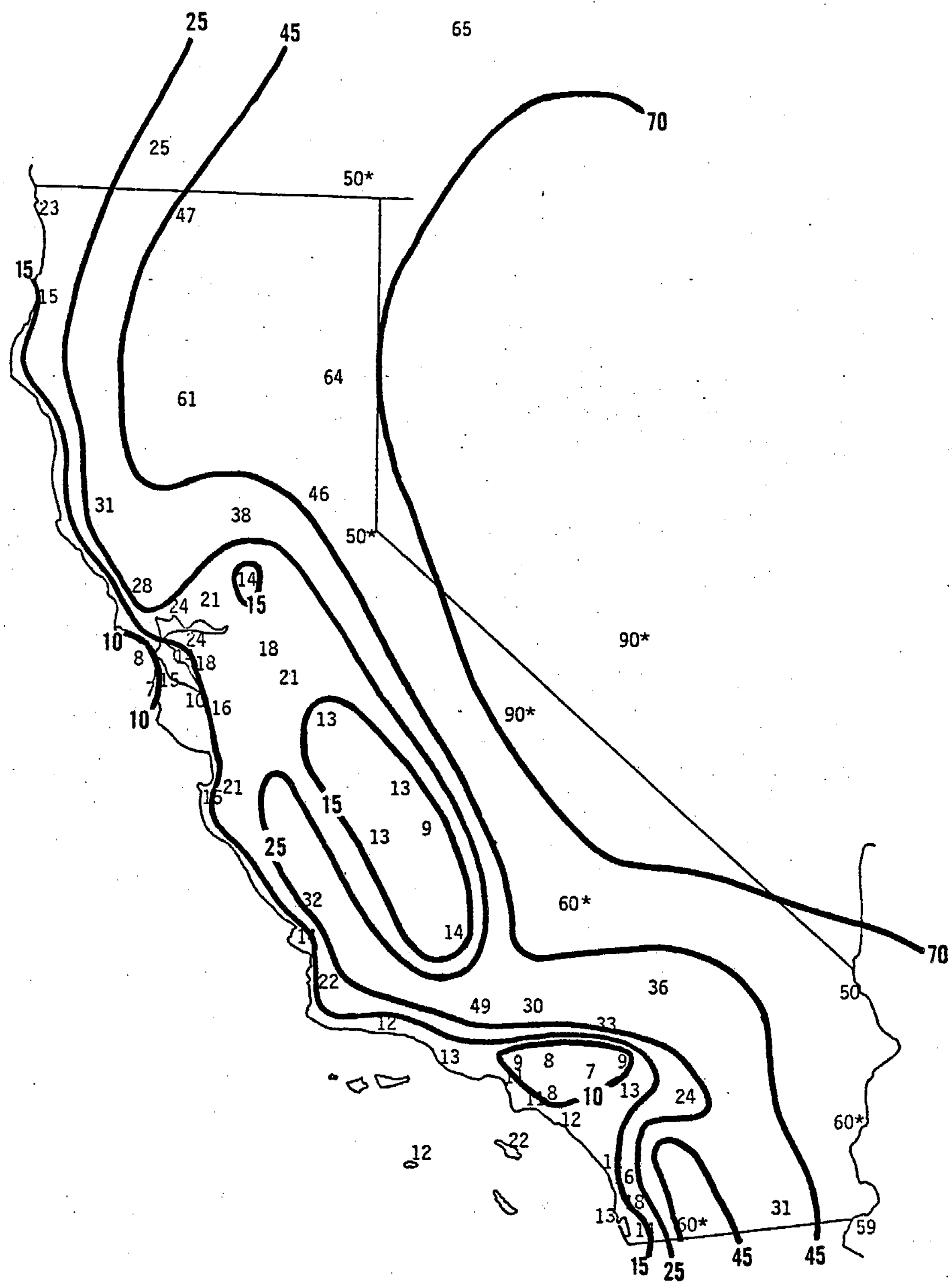

Figure 3.5 Median 1 PM visibilities (in miles) and visibility isopleths for California.

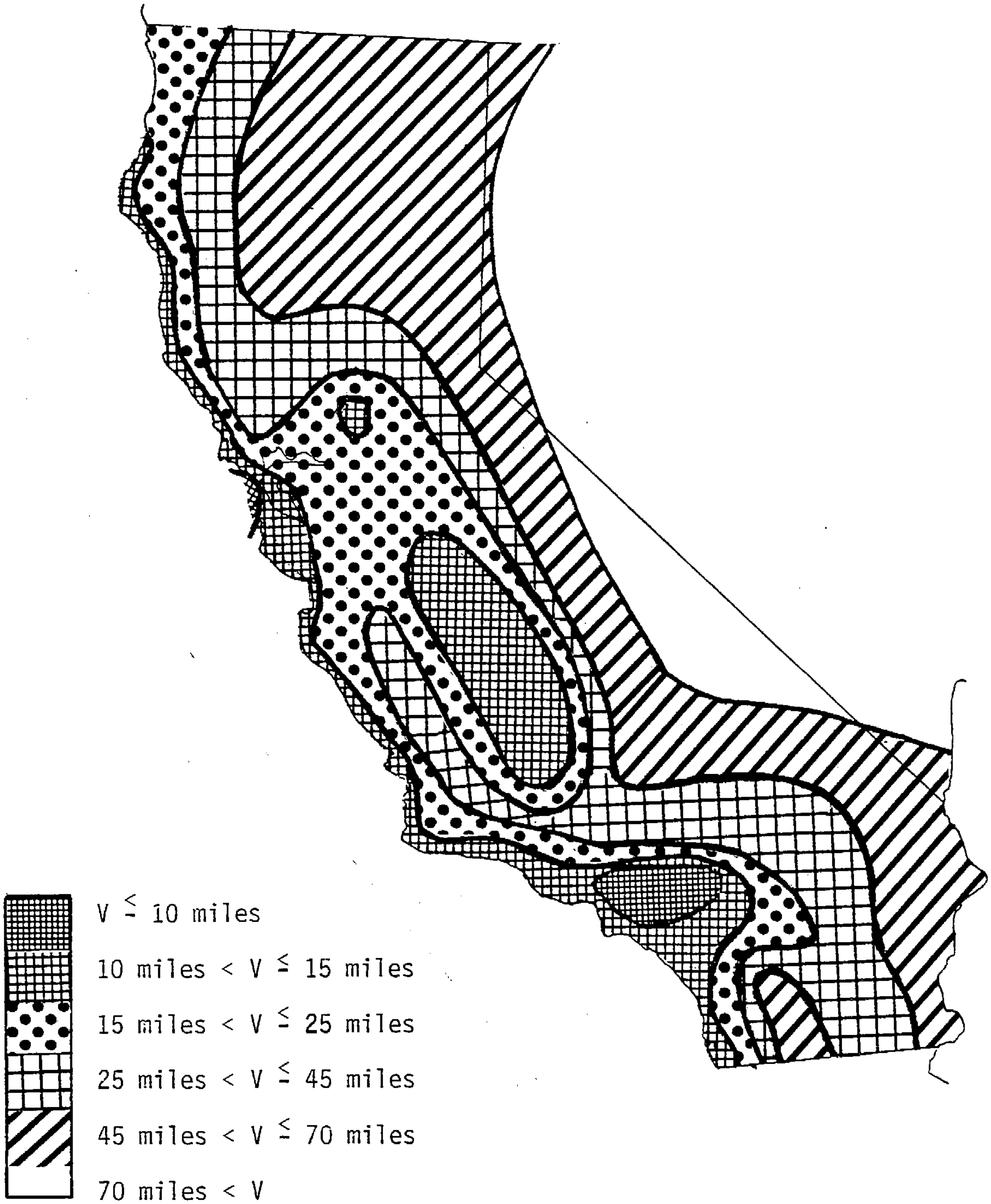

Figure 3.6 Shaded isopleth map for median 1 PM visibilities in California.

visual range. The major component of aerosol extinction is usually light-scattering by secondary aerosols (those formed from gas-to-particle conversion in the atmosphere). The routine monitoring data of interest for comparison with visibility are thus the measurements of total suspended particulate mass (TSP) as well as the measurements of secondary aerosols, such as sulfates and nitrates.* The emissions of interest are emissions of primary particles as well as emissions of gaseous precursors to secondary aerosols: sulfur oxides (SO_x), nitrogen oxides (NO_x), and reactive hydrocarbons (RHC).

Figures 3.7, 3.8, and 3.9 -- based on one year of data (April 1976 through March 1977) from state and local particulate monitors -- illustrate the spatial patterns in annual mean concentrations of TSP, sulfate, and nitrate, respectively. Qualitatively, there is a basic agreement between visibility patterns and the concentration patterns for sulfate and nitrate in the sense that the San Joaquin Valley and South Coast Air Basins, the two major pockets of low visibility, are obvious hot-spots for sulfate and nitrate. Although TSP concentrations also tend to be highest in the San Joaquin Valley and South Coast Air Basins, the spatial patterns in TSP do not seem to correspond quite as well with the visibility variations as do the spatial patterns in sulfate and nitrate. Concentrations of TSP exhibit less well-defined large-scale spatial gradients than visibility, sulfates, or nitrates, probably due to the substantial effect that local dust sources often exert on TSP.

It should be noted that the above observations are consistent with Chapter 6 of this report (Visibility/Aerosol Relationships), where we find that secondary aerosols are the dominant contributors to atmospheric extinction in California. Also, the correspondence between the aerosol spatial patterns and the visibility patterns suggests that the major pockets of low visibility in California are caused by air quality variations rather than purely natural factors, such as fog, relative humidity, or precipitation. Furthermore, considering the spatial distribution

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*The reader is referred to Section 6.1.4 for discussions of the substantial uncertainties that exist in nitrate measurements and the possibility that nitrate measurements may be acting as surrogates for various photochemical aerosols rather than representing nitrate aerosol per se in our analyses.

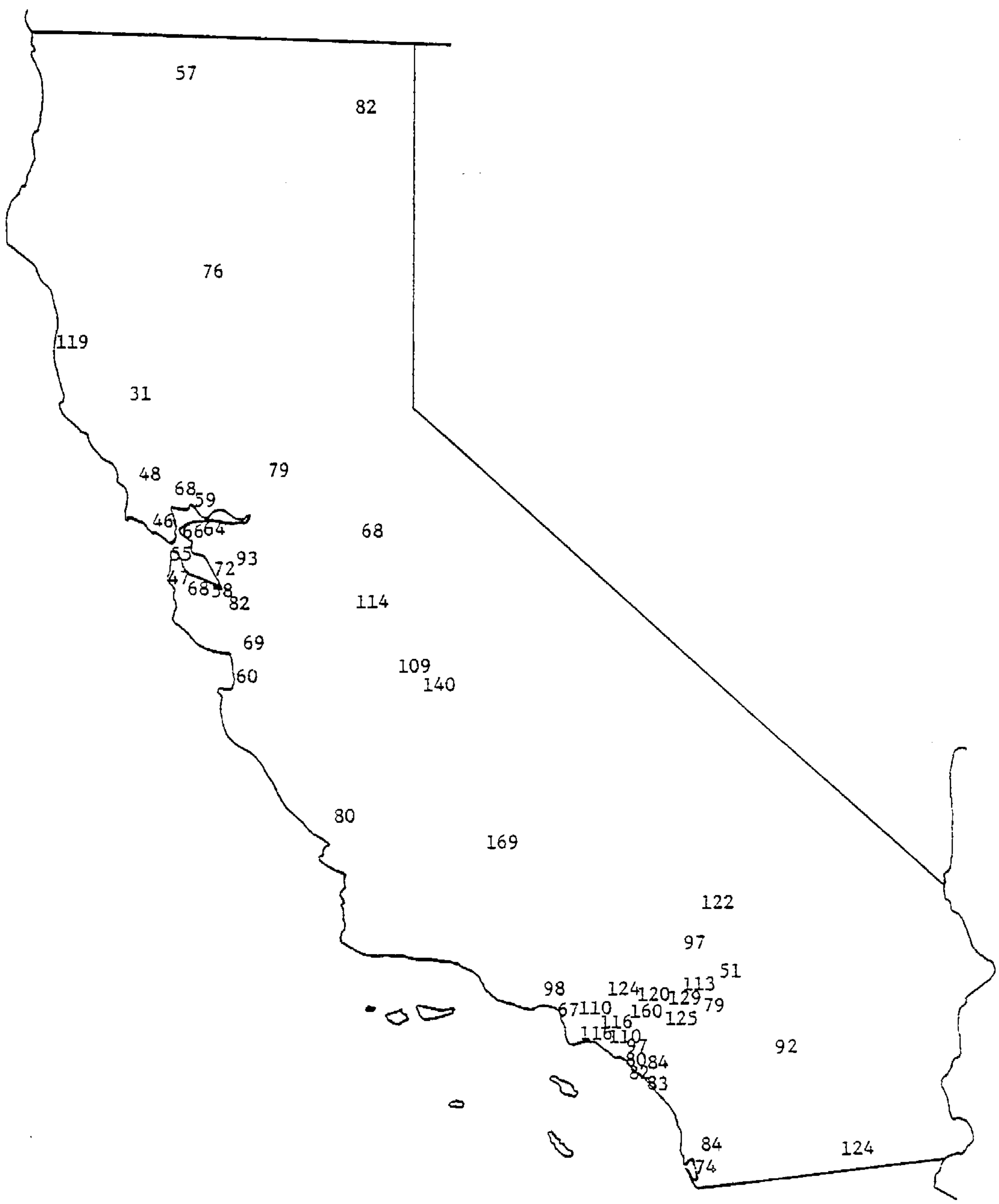

Figure 3.7 Annual mean TSP concentrations for California in μg/m³ (April 1976 - March 1977).

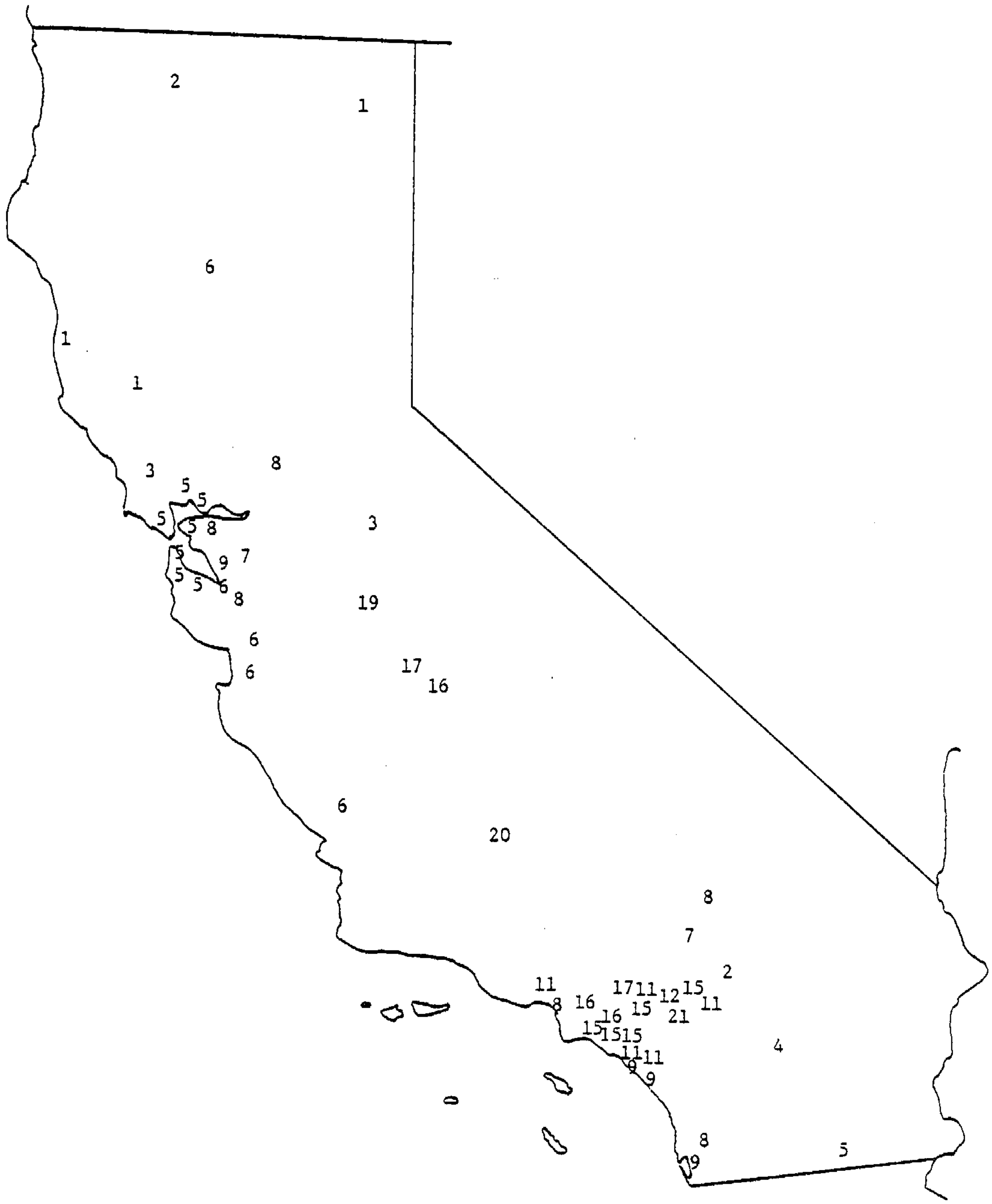

Figure 3.9 Annual mean nitrate concentrations for California in $\mu g/m^3$ (April 1976 - March 1977).

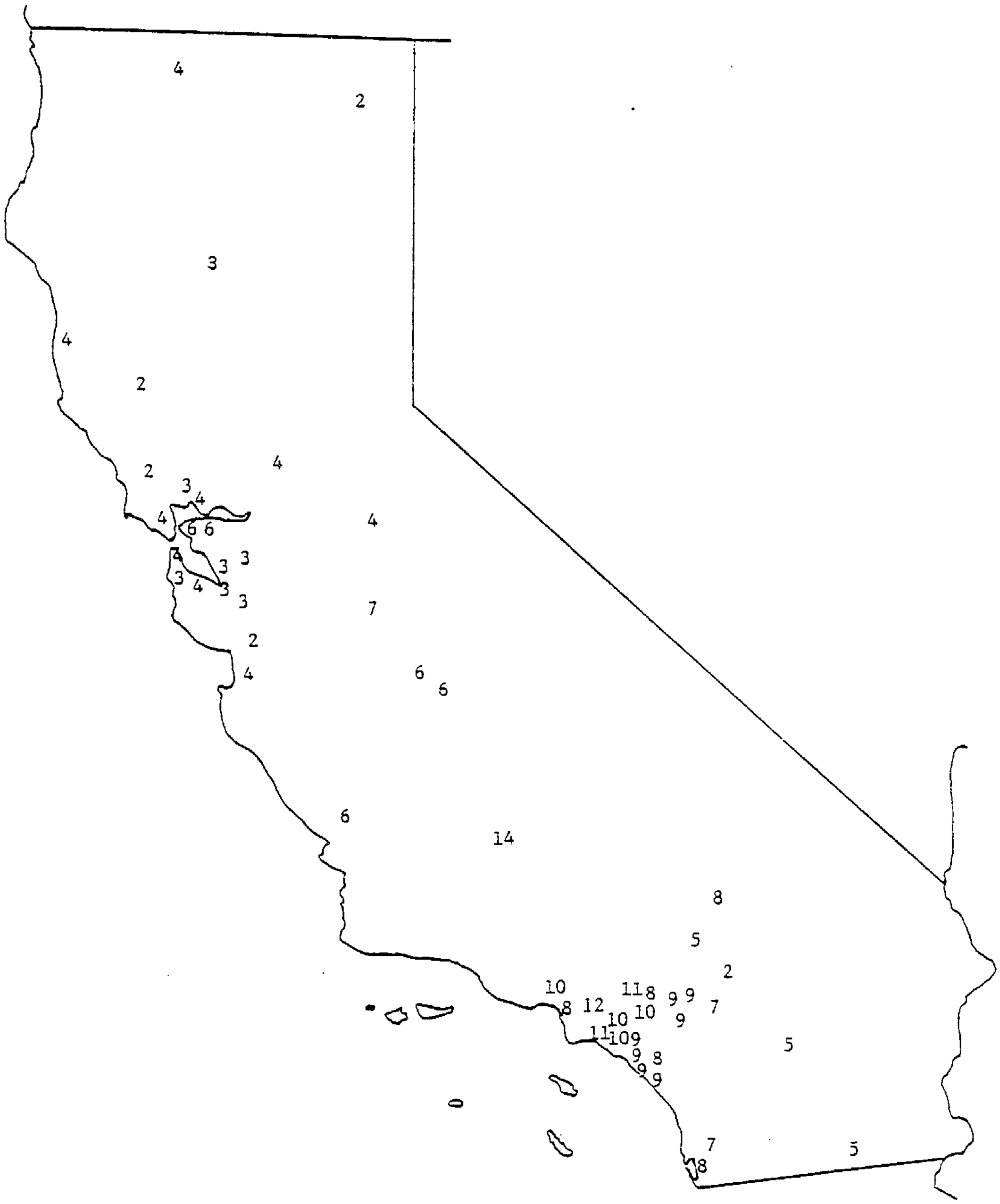

Figure 3.8 Annual mean sulfate concentrations for California in $\mu g/m^3$ (April 1976 - March 1977).

of anthropogenic emissions (see following paragraphs), it seems obvious that the air quality variations basically stem from man-made sources.

Figures 3.10 through 3.13 illustrate the spatial distribution of particulate, SO_2, NO_x, and RHC emissions, respectively. As evidenced by Figures 3.10 through 3.13, the pockets of low visibility in California (e.g. the San Joaquin Valley and South Coast Air Basins) appear to be related more closely to the spatial distribution of secondary aerosol precursor emissions (especially SO_x) than to the spatial distribution of primary particulate emissions.

Considering the spatial distribution of emissions, as well as climatological variations, we can speculate on the specific causes for the major pockets of poor visibility in California. The extremely low visibilities in the central and eastern parts of the South Coast Air Basin are likely caused by the high concentration of SO_x, NO_x, and RHC emissions in that air basin, with the problem exacerbated by the relatively low wind speeds, strong inversion layers, and intense sunlight (leading to high photochemical aerosol production rates) characteristic of Los Angeles (NOAA 1977; Bell 1958). The shape of the visibility isopleths in Southern California also suggests that, under the prevailing westerly winds (Bell 1958), the visibility impacts of emissions from the South Coast Air Basin extend well into the Southeast Desert Air Basin. The large pocket of low visibility in the central/southern San Joaquin Valley may be related to several factors: (1) the relatively high level of SO_x emissions in that area, (2) the relatively long residence of air parcels in the San Joaquin Valley (Bennett 1978) which allows greater time for secondary aerosol formation and accumulation, (3) the transport of secondary aerosol precursors from the large concentration of emissions in the San Francisco Bay Area, and (4) particulate matter from agricultural burning and dust sources.

It is interesting to note that the high density of aerosol precursor emissions in the San Francisco Bay Area produces neither a very great perturbation in local visibility nor very large concentrations of sulfate and nitrate. This paradox might be explained by three factors: (1) sunlight intensity is relatively low compared to Southern California (NOAA 1977), leading to slower formation rates for photochemical aerosols in the Bay Area;

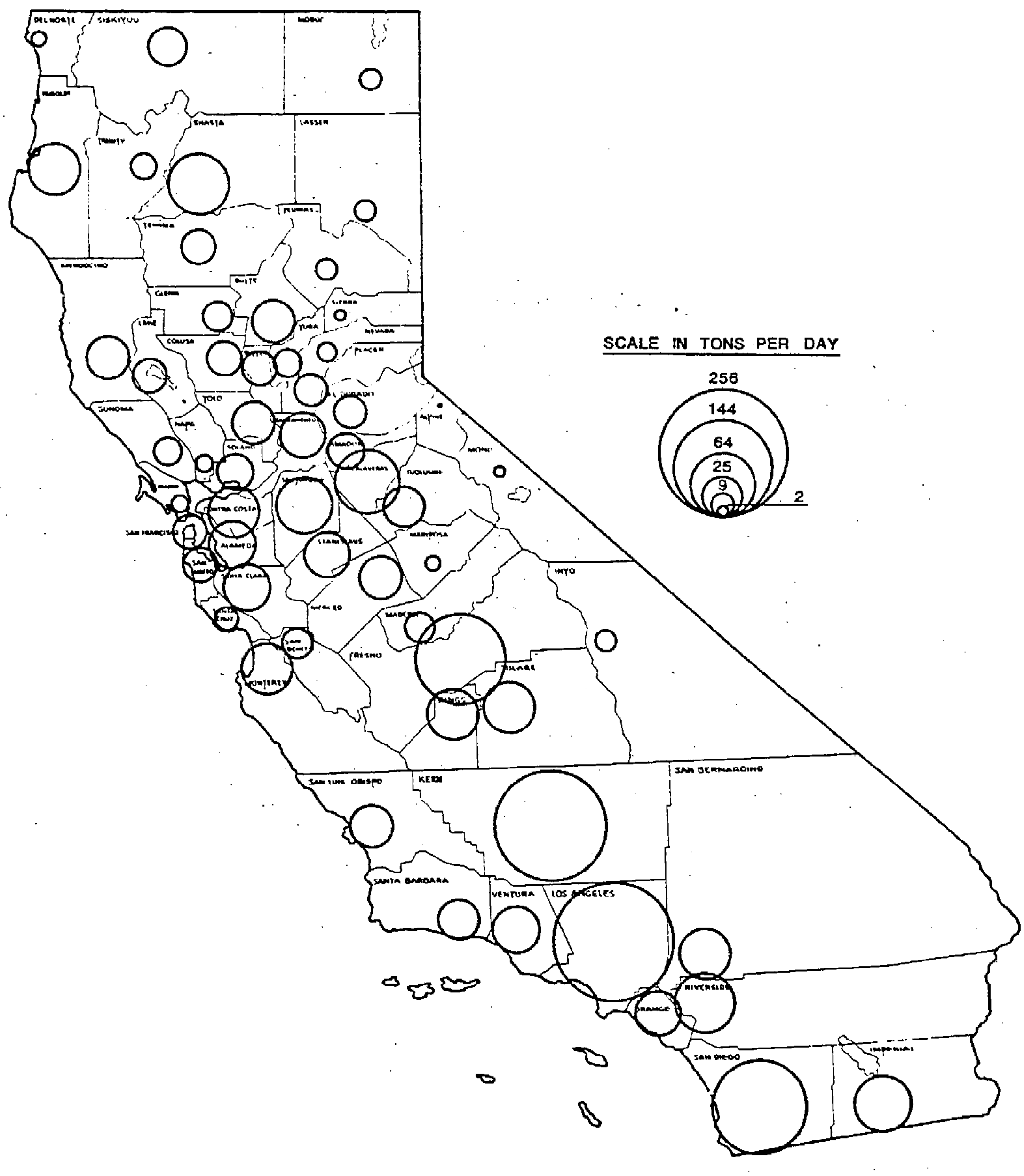

Figure 3.10 Spatial distribution of particulate emissions in California (ARB, 1978).

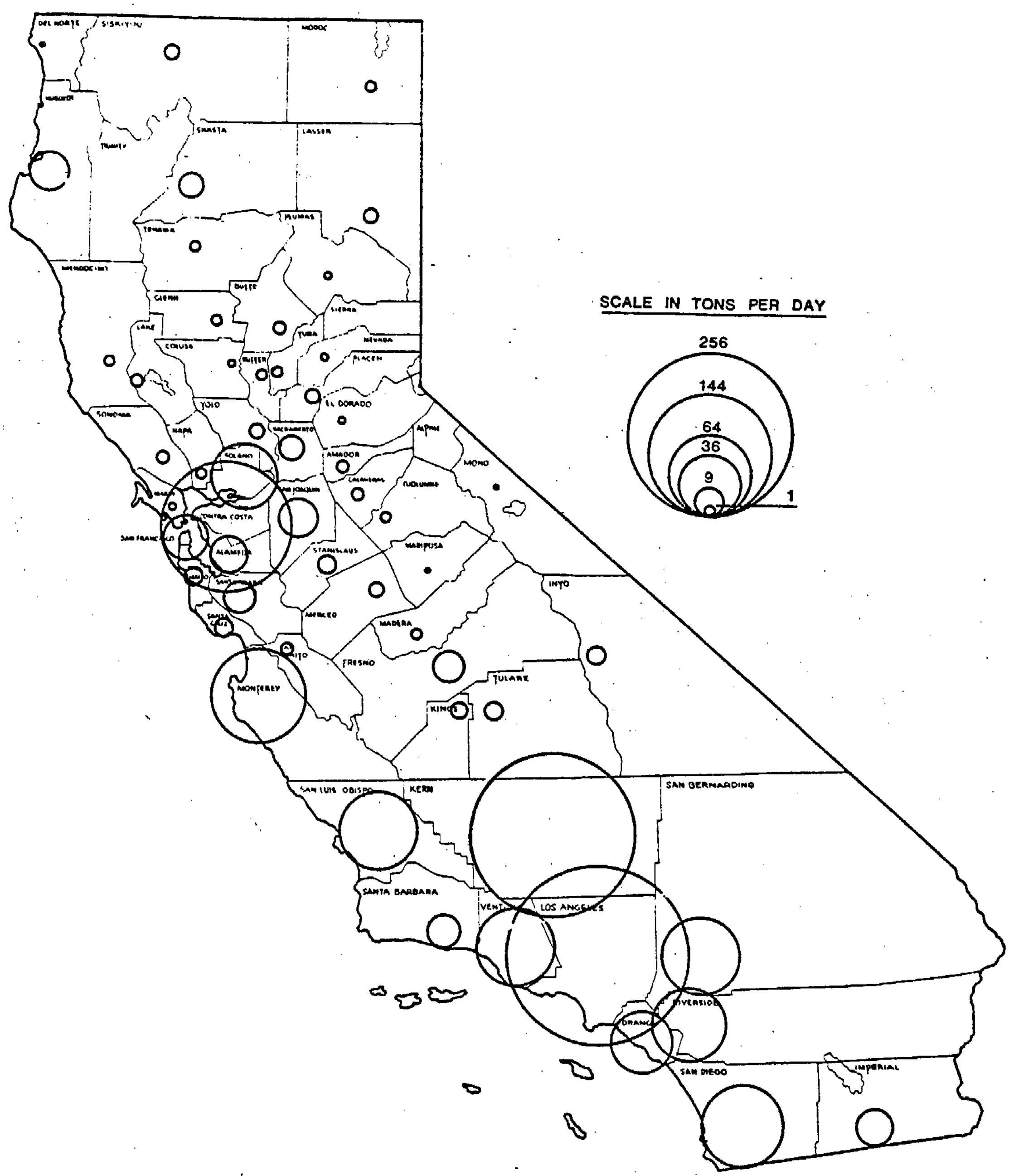

Figure 3.11 Spatial distribution of SO_2 emissions in California (ARB, 1978).

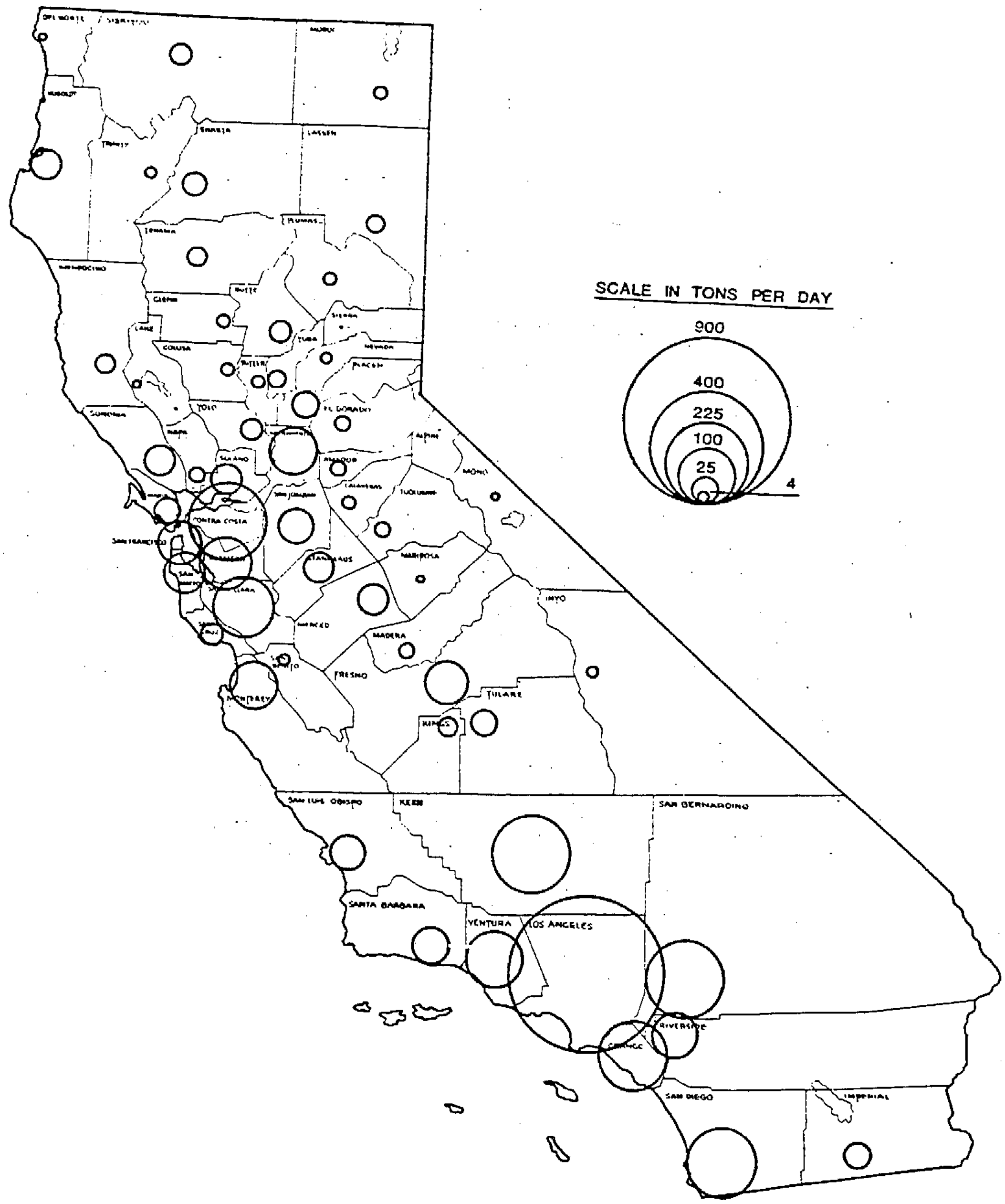

Figure 3.12 Spatial distribution of NO_x emissions in California (ARB, 1978).

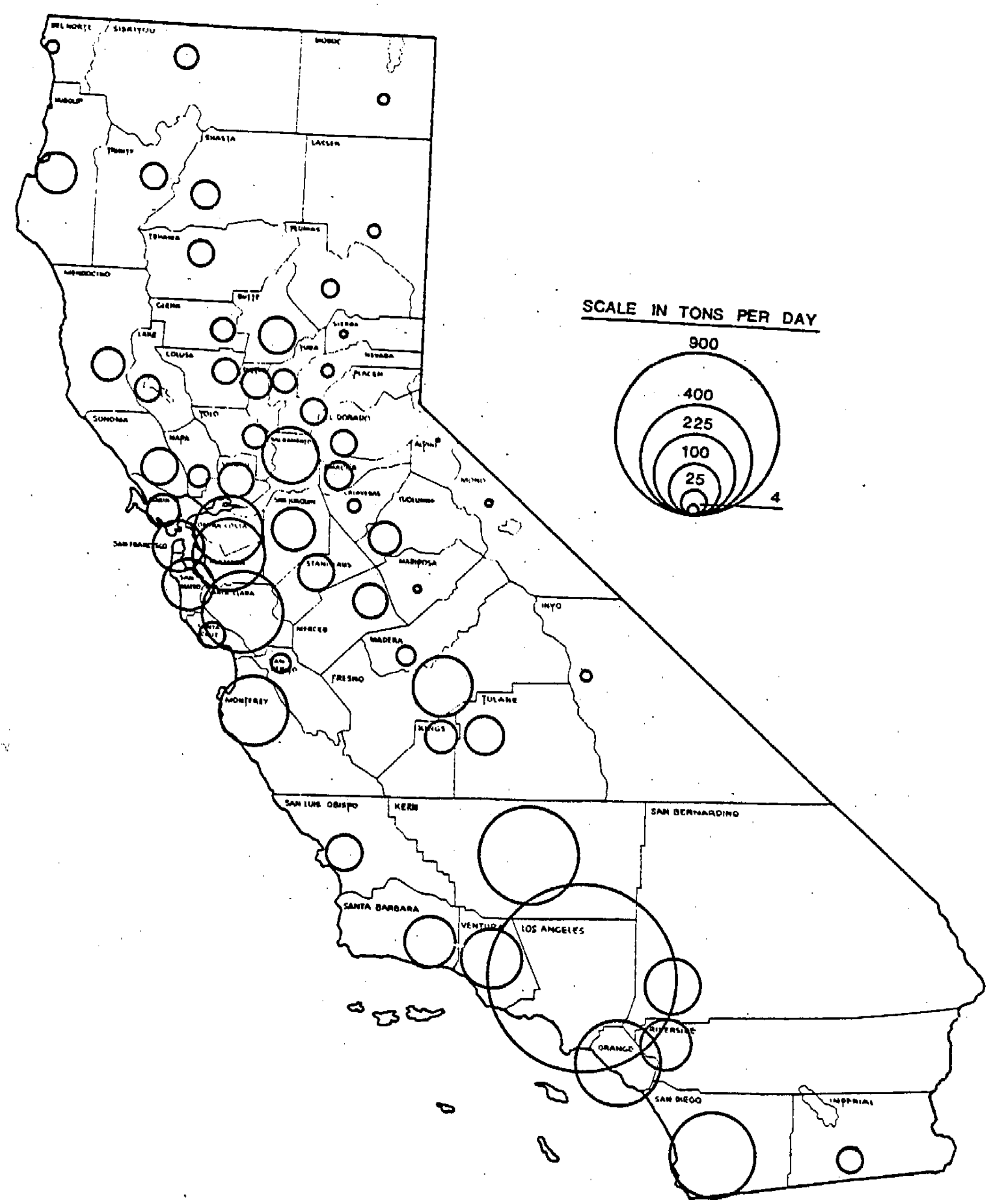

Figure 3.13 Spatial distribution of reactive organic emissions in California (ARB, 1978).

(2) wind speeds are relatively high in the Bay Area (NOAA 1977; Bell 1958), tending to move the precursor emissions into the Central Valley rather quickly; and (3) much if not most of the Bay Area emissions are located in the downwind (eastern) portion of that air basin. The shape of the visibility isopleths east of the Bay Area suggests that the principal visibility impact of Bay Area emissions may tend to be a diluted effect occurring in the Central Valley rather than a concentrated effect occurring locally.*

3.1.5 Natural Visibility Levels in Los Angeles

The California visibility isopleth map affords us a chance to address the often asked question: "What is the natural or pristine level of visibility in the Los Angeles area?". Based on data for other locations in southern California which are under lesser influence by man-made sources, we venture the following very speculative remarks:

- Median 1:00 PM visibility along the Los Angeles coastline, approximately 11 miles based on data for Santa Monica and Long Beach, would probably not be greatly better under natural conditions. All other shoreline stations south of the San Francisco area (Monterey, San Luis Obispo, Santa Barbara, Oxnard, San Nicolas, Newport, Camp Pendleton, Carlsbad, and San Diego International) report median visibilities of 12-16 miles. Even acknowledging some level of man-made impact at these other locations, it seems improbable that the natural median visibility level at shoreline sites in Los Angeles would be greater than 15 to 20 miles.

- Median 1:00 PM visibility in the central and inland parts of the South Coast Air Basin would probably be much better under natural conditions than the existing level of 7-9 miles. Other south or south/central California locations at comparable distances from the coastline -- Salinas, Paso Robles, Santa Maria, NE San Diego, and S San Diego -- report median visibilities of 21, 32, 22, 18, and 14 miles respectively. Based on these observations we conjecture that the natural median visibility levels in the central and inland valleys of the South Coast Air Basin might be on the order of 15 to 30 miles. This estimate may be low if the comparison locations are also significantly affected by man-made sources; however, the estimate may be high if the generally lower elevation of the Los Angeles Basin relative to the other sites leads to more natural fog and haze than occurs at the other locations.

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*Actually, wind speeds in the southern part of the Bay Area (near San Jose) are lower than in the northern part of the Bay Area; this leads to more detectable local visibility impacts in the southern Bay Area than exist in the northern Bay Area.

3.2 BEST-CASE AND WORST-CASE VISIBILITIES

In addition to median visibility, it is of interest to examine best-case and worst-case conditions. Table 3.2 lists (best) 10th percentile, median, and (worst) 90th percentile visibilities for the years 1974-1976 at the 67 study locations. It should be noted that, for most locations, the cumulative frequency distributions of visibility had to be extrapolated to estimate the 10th percentiles. Where such extrapolations are notably uncertain, the 10th percentiles are marked with an asterisk. At a few locations, the uncertainties are so great that we did not venture any estimate of the 10th percentile.

Figures 3.14 and 3.15 present isopleth maps for 10th percentile and 90th percentile visibilities, respectively. The 10th and 90th percentiles display spatial patterns that have the same general shape as the spatial patterns in median visibility (Figures 3.5 and 3.6). Specifically, the best visibility occurs along the California-Nevada border; visibility generally declines as one moves from the eastern border towards the coast; and two significant pockets of low visibility occur between eastern California and the coast: the San Joaquin Valley/lower Sacramento Valley area, and (especially) the Los Angeles basin.

One major difference among the visibility percentiles is that worst-case visibility exhibits more severe spatial gradients than median visibility which in turn shows stronger spatial gradients than best-case visibility (compare Figures 3.5, 3.14, and 3.15). For example, the highest 90th percentile values ($\sim$ 50 miles) along the Nevada border fall by a factor of 17 (to $\sim$ 3 miles) in the central/southern San Joaquin Valley and by a factor of 25 (to $\sim$ 2 miles) in the eastern portions of the Los Angeles basin. The highest medians ($\sim$ 80 miles) along the Nevada border drop by a factor of 6 (to $\sim$ 13 miles) in the central/southern San Joaquin Valley and by a factor of 10 (to $\sim$ 8 miles) in the eastern portions of the Los Angeles basin. The highest 10th percentiles ($\sim$ 120 miles) along the Nevada border fall only by a factor of 4 (to $\sim$ 30 miles) in both the central/southern San Joaquin Valley and the Los Angeles basin.

A corollary of the less intense spatial gradients in (best) 10th percentile visibility is that most parts of California do experience some very

TABLE 3.2 BEST-CASE 10TH, MEDIAN, AND WORST-CASE 90TH PERCENTILES OF VISIBILITY FOR 1974-1976.

AIR BASIN, Site	VISIBILITY PERCENTILES (MILES)		
	Best 10th Percentile	Median	Worst 90th Percentile
NORTH COAST			
Arcata	22	15	3
Crescent City	43	23	3
Ukiah	45*	31	15
SACRAMENTO VALLEY			
Marysville	85	38	5
Red Bluff	120*	61	10
Sacramento	42	14	4
NORTHEAST PLATEAU AND SOUTHERN OREGON			
Burns	100*	65	33
Lakeview	NE	50*	20
Medford	45*	25	5
Montague	75*	47	20
Susanville	85*	64	40
MOUNTAIN COUNTIES AND LAKE TAHOE			
Blue Canyon	75	46	6
South Lake Tahoe	NE	50*	12
SAN FRANCISCO BAY AREA			
Concord	45*	24	7
Fairfield	48	21	6
Hayward	50	18	5
Napa	42	24	6
Oakland	31	14	5

TABLE 3.2 BEST-CASE 10TH, MEDIAN AND WORST-CASE 90TH PERCENTILES OF VISIBILITY FOR 1974-1976. (Continued)

AIR BASIN, Site	VISIBILITY PERCENTILES (MILES)		
	Best 10th Percentile	Median	Worst 90th Percentile
Pillar Point	15	7	2
San Francisco Int.	46	15	6
San Francisco PBS	15	8	3
San Jose	45	16	6
Santa Rosa	60*	28	6
Sunnyvale	18	10	5
NORTH CENTRAL COAST			
Monterey	35	15	6
Salinas	37	21	9
SAN JOAQUIN VALLEY			
Bakersfield	35	14	3
Fresno	28	13	3
Lemoore	25*	13	3
Merced	30*	13	3
Modesto	46	21	4
Stockton	43	18	4
Visalia	20	9	3
GREAT BASIN VALLEYS AND WESTERN NEVADA			
Bishop	120*	90*	55
Tonopah	NE	90*	52
SOUTH CENTRAL COAST			
Oxnard	40	13	3
Paso Robles	57	32	9
San Luis Obispo	24	14	5
Santa Barbara	42	12	4
Santa Maria	41	22	7

TABLE 3.2 BEST-CASE 10TH, MEDIAN AND WORST-CASE 90TH PERCENTILES OF VISIBILITY FOR 1974-1976. (Continued)

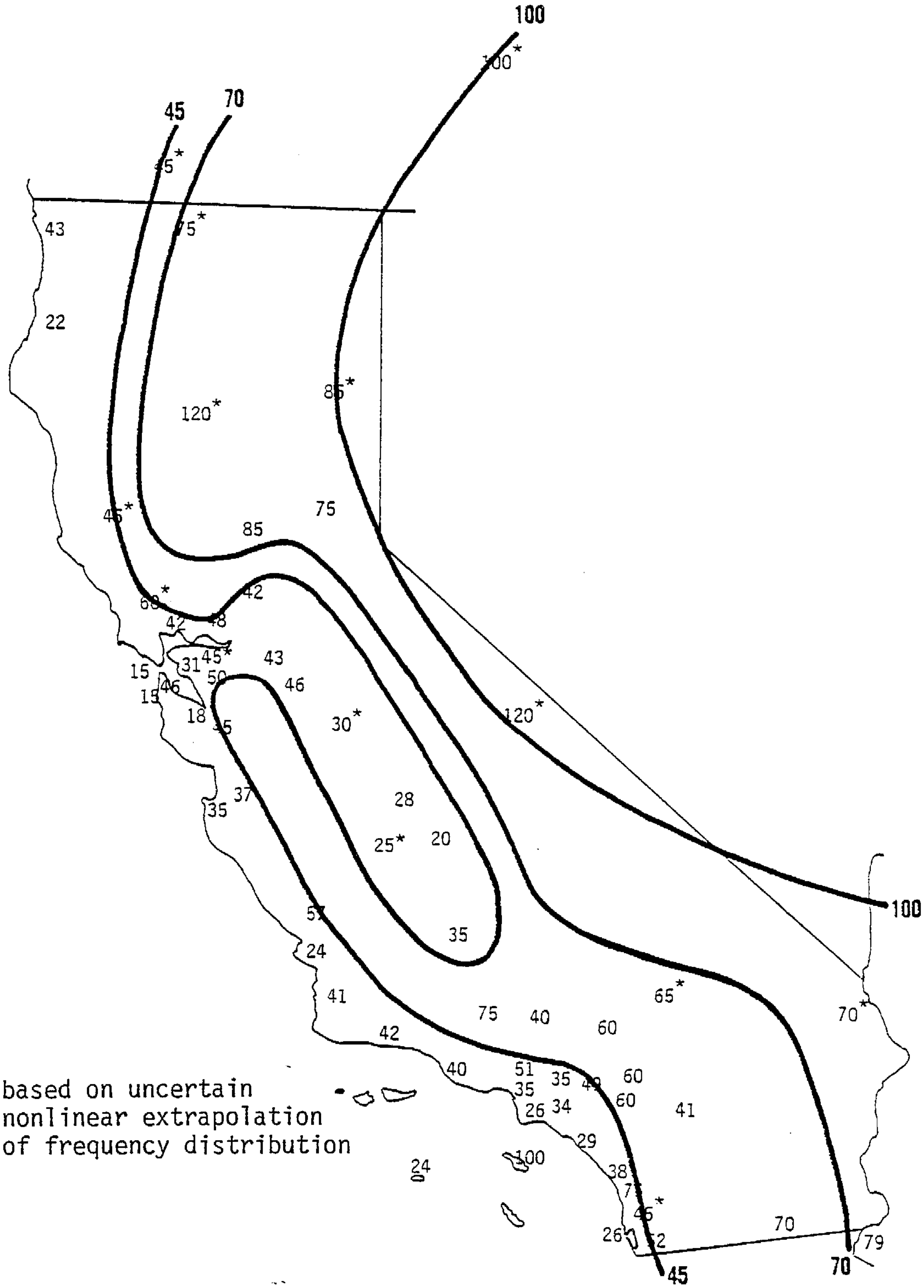
AIR BASIN, Site	VISIBILITY PERCENTILES (MILES)		
	Best 10th Percentile	Median	Worst 90th Percentile
SOUTH COAST (Coastal Part)			
Fullerton	34	8	2
Long Beach	26	11	4
Newport Beach	29	12	3
San Nicolas	42	12	5
Santa Catalina	100	22	2
Santa Monica	35	11	3
SOUTH COAST (Inland Part)			
Burbank	51	9	3
El Monte	35	8	3
Ontario	49	7	2
San Bernardino	60	9	2
Sandberg	75	49	22
SE Riverside	60	13	3
SAN DIEGO			
Campo	NE	60*	28
Camp Pendleton	38	12	5
Carlsbad	75	16	5
NE San Diego	45*	18	6
San Diego	26	13	5
S San Diego	52	14	6
SOUTHEAST DESERT AND WESTERN ARIZONA			
Barstow	65*	36	20
Blythe	NE	60*	31

TABLE 3.2 BEST-CASE 10TH, MEDIAN AND WORST-CASE 90TH PERCENTILES OF VISIBILITY FOR 1974-1976. (Continued)

AIR BASIN, Site	VISIBILITY PERCENTILES (MILES)		
	Best 10th Percentile	Median	Worst 90th Percentile
China Lake	NE	60*	30
Imperial	70*	31	10
Lancaster	40	30	16
Needles	70*	50	30
Palm Springs	41	24	12
Victorville	60	33	16
Yuma	79	59	24

* = based on uncertain nonlinear extrapolation of frequency distribution.

NE = Not estimated because of excessive uncertainty in extrapolating the frequency distribution.



* = based on uncertain nonlinear extrapolation of frequency distribution

Figure 3.14 Best 10th percentile 1 PM visibilities (in miles) in California, 1974-1976.

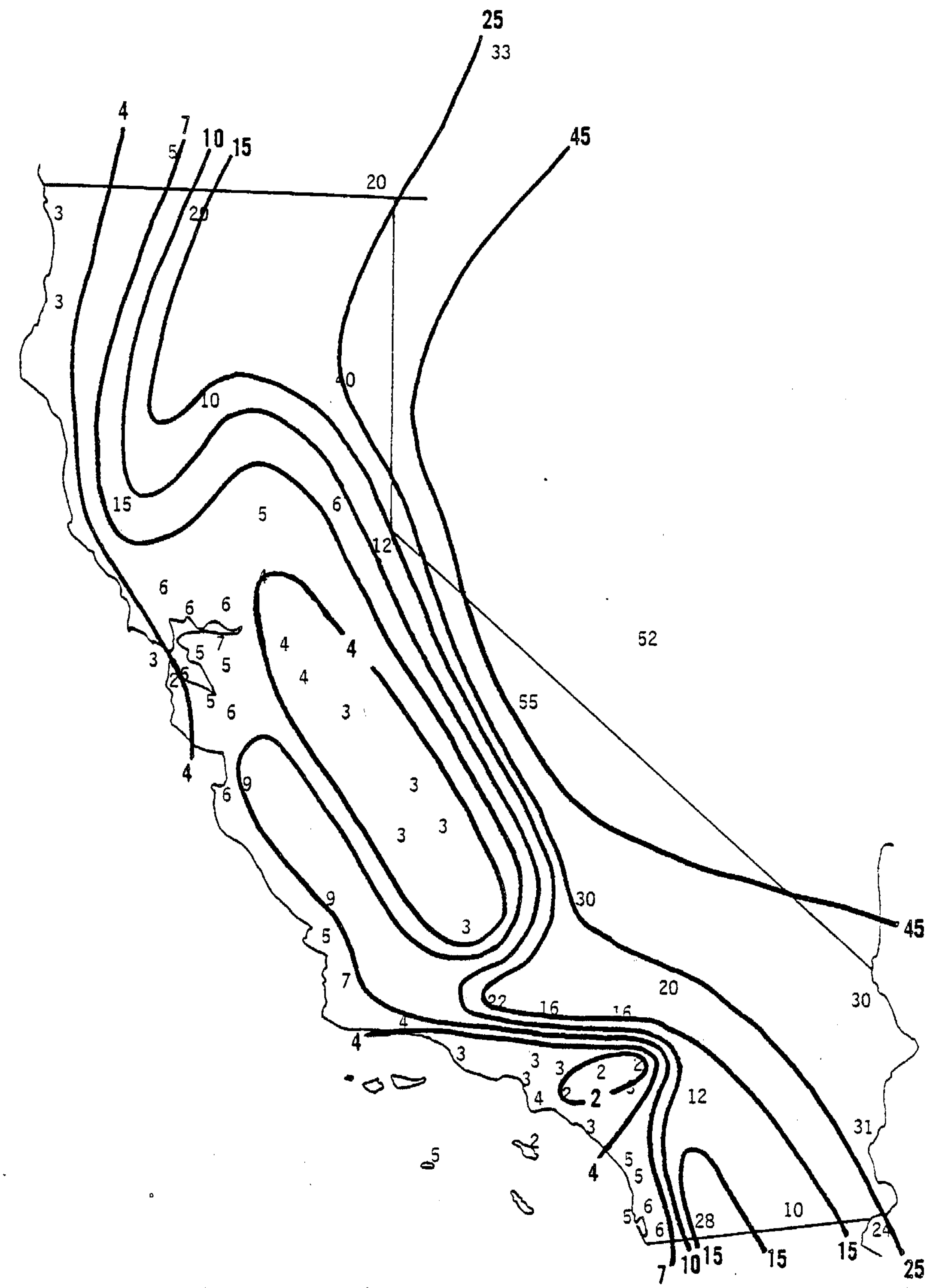


Figure 3.15 Worst 90th percentile 1 PM visibilities (in miles) in California, 1974-1976.

clear days. With the exception of a few sites along the coast, the central/southern San Joaquin Valley, and some locations in Los Angeles, nearly the entire state of California has a 10th percentile exceeding 40 miles. Even the eastern portion of the Los Angeles basin, which exhibits a 90th percentile of only 2 miles, and a median of only 8 miles, displays a 10th percentile on the order of 50 to 60 miles.

3.3 METEOROLOGICALLY ADJUSTED VISIBILITIES

In order to gain a better understanding of natural versus man-made influences on visibility, it is worthwhile to stratify the data according to meteorology. Figure 3.16 illustrates meteorologically sorted median 1:00 PM visibilities for 1974-1976. Twenty-four* sites for which we have computerized records are included in Figure 3.16. The meteorological stratification is according to weather Class III: no fog, precipitation, or blowing dust/snow; wind speed less than 12 knots; and 40% ≤ relative humidity < 70%.

In far-northern California, the meteorologically sorted data (Figure 3.16) exhibit milder spatial gradients than the unsorted data (Figure 3.5). For example, visual range changes from 55 miles at the northern Nevada border to 20 miles at Arcata for the meteorologically sorted data, as compared to 70 miles at the northern Nevada border to 15 miles at Arcata for the unsorted data. This indicates that meteorological stratification does partly discount for natural sources and climatological variances. That meteorological stratification does not completely discount for natural influences seems evident from the fact that significant coast-to-inland gradients still appear in the meteorologically sorted data for northern California; based on the emission densities (see Figures 3.10 through 3.13) we would not expect such large gradients to arise from man-made sources alone. The natural influences which remain in the weather-sorted data could include sea spray haze, natural organic haze, and relative humidity gradients (within the 40% to 70% range).

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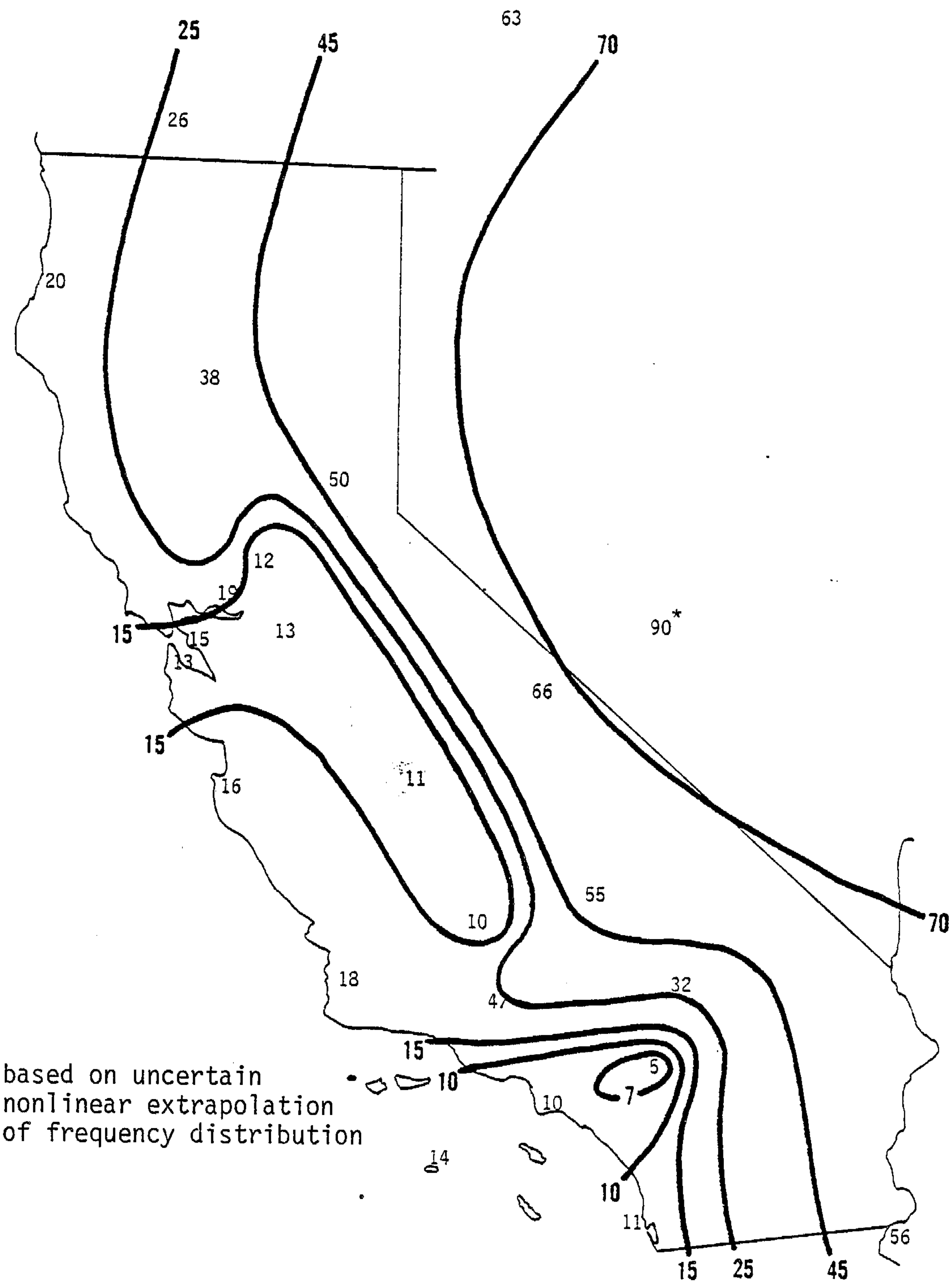
*These are the 21 sites where we have computerized 1974-1976 records (see Figure 2.1), plus Fairfield, Monterey, and San Bernardino where we have computerized 1968-1970 records. For the three sites with 1968-1970 data, a very slight adjustment has been made to account for visibility trends between 1968-1970 and 1974-1976.



* = based on uncertain nonlinear extrapolation of frequency distribution

Figure 3.16 Median 1 PM visibilities (in miles) for meteorological Class III.

It is interesting to note that meteorological stratification slightly intensifies the pockets of poor visibility in the San Joaquin Valley/southern Sacramento Valley and the eastern Los Angeles Basin. For the unstratified data, median visual range drops from 70-90 miles along the Nevada border to 13-18 miles in the San Joaquin Valley (a factor of 5) and to 7-9 miles in the eastern Los Angeles Basin (a factor of 10). For the meteorologically sorted data, median visibility drops from 60-70 miles along the Nevada border to 10-13 miles in the San Joaquin Valley (a factor of 6) and to 5 miles in the eastern Los Angeles basin (a factor of 13). This result strongly supports our earlier hypothesis that the low visibilities in the San Joaquin/ Sacramento Valley and the Los Angeles basin are due primarily to man-made sources.

4.0 SEASONAL PATTERNS OF VISIBILITY

Visibility in many parts of California displays pronounced seasonal variations. This chapter characterizes the seasonal variations by examining data stratified according to the four quarters of the year. Section 4.1 illustrates the seasonal visibility patterns using all the data for 1974-1976 (with no sorting for meteorology). In Section 4.2, some of the causes for the seasonal patterns are investigated by performing meteorological stratification of the visibility data and by analyzing quarterly data for aerosol concentrations.

4.1 DESCRIPTION OF SEASONAL PATTERNS

Figure 4.1 illustrates the seasonal patterns in median 1:00 PM visibility for 1974-1976 at the study locations. Figures 4.1a, 4.1b, and 4.1c are for northern, central, and southern California respectively; each figure is organized by air basins, proceeding from western regions to eastern regions across the page. The data points marked by asterisks are based on uncertain extrapolation of the visibility frequency distributions.*

It is obvious from Figure 4.1 that the seasonal pattern in visibility is not uniform throughout California. The seasonal patterns are usually consistent, however, within individual air basins and major geographical sections of California. Nearly all locations in southern California and along the central coast -- the South Coast, San Diego, Southeast Desert, South Central Coast, and North Central Coast Air Basins -- exhibit minimum visibilities during the spring (second quarter) or summer (third quarter), especially the summer, and maximum visibility during the fall (fourth quarter) and winter (first quarter). Nearly all locations in the San Joaquin Valley, Sacramento Valley, and San Francisco Bay Area Air Basins exhibit a distinct maximum in visibility during the spring with minimums during the fall and winter; a similar pattern exists in the Northeast Plateau Air Basin (as well

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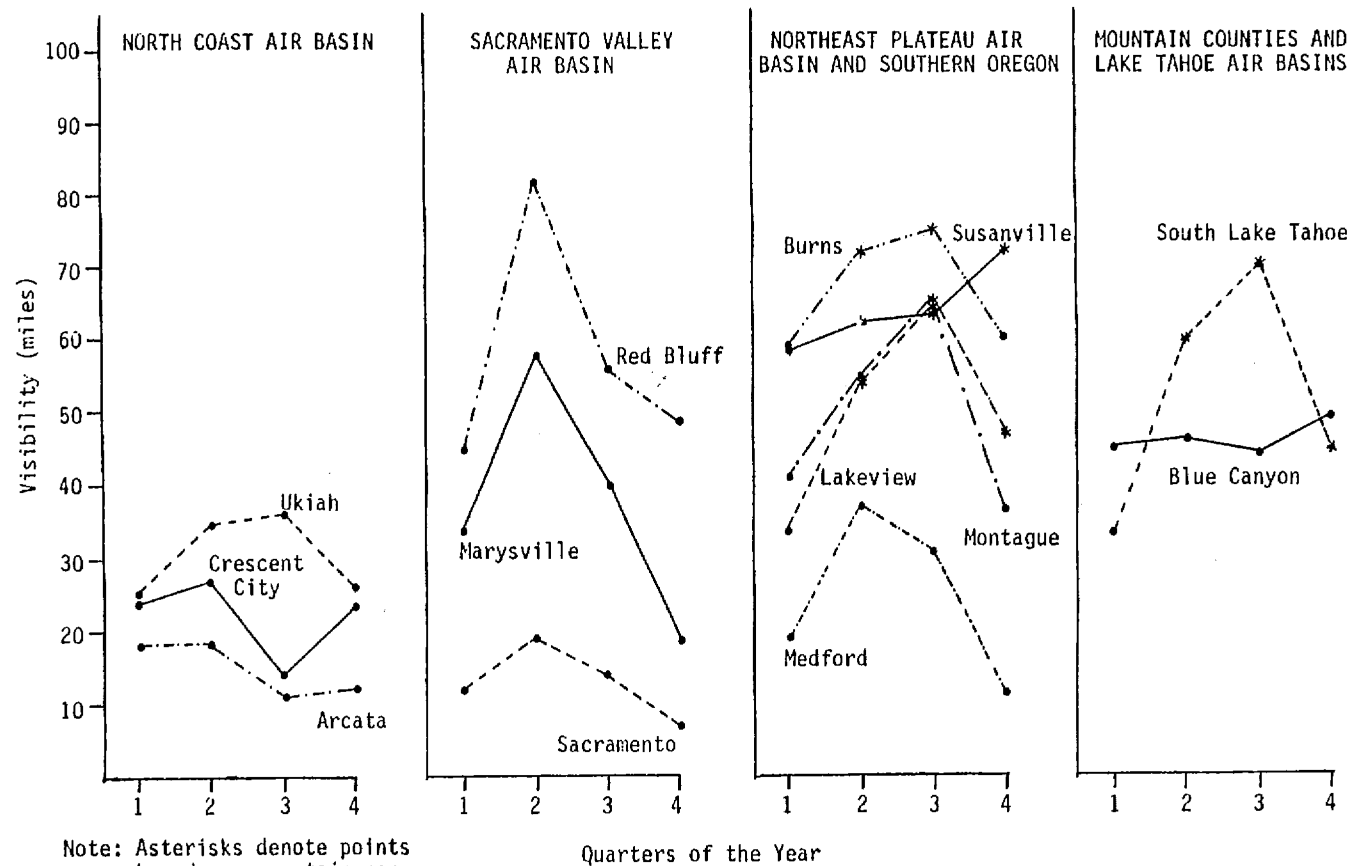
*Two sites, Campo and Tonopah, were excluded from Figure 4.1 because the extrapolation of the seasonal visibility distributions was extremely uncertain.



Note: Asterisks denote points based on uncertain non-linear extrapolation of frequency distributions.

Figure 4.1a Northern California

Figure 4.1 Seasonal patterns in California visibility, median 1:00 PM values, 1974-1976.

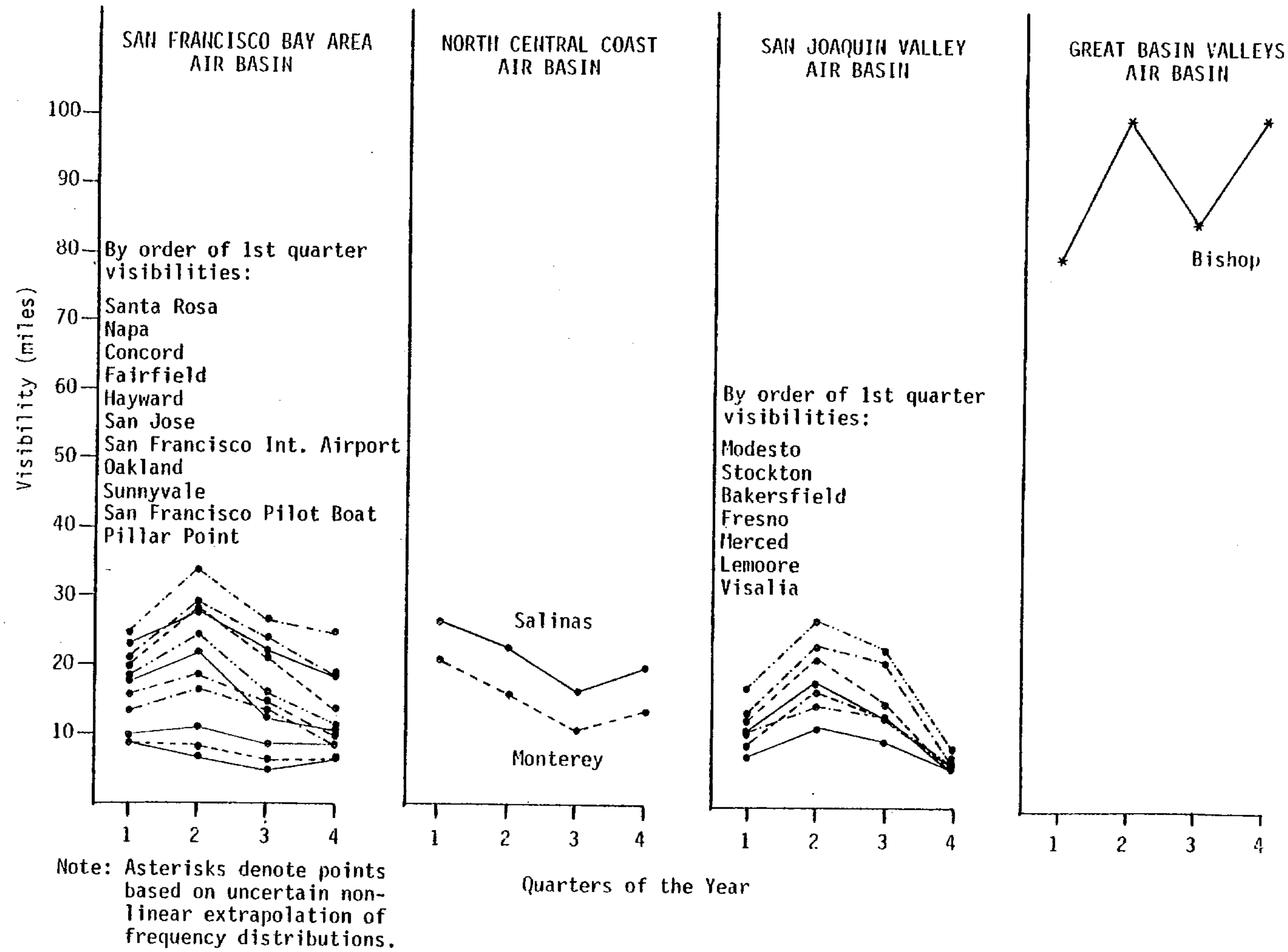
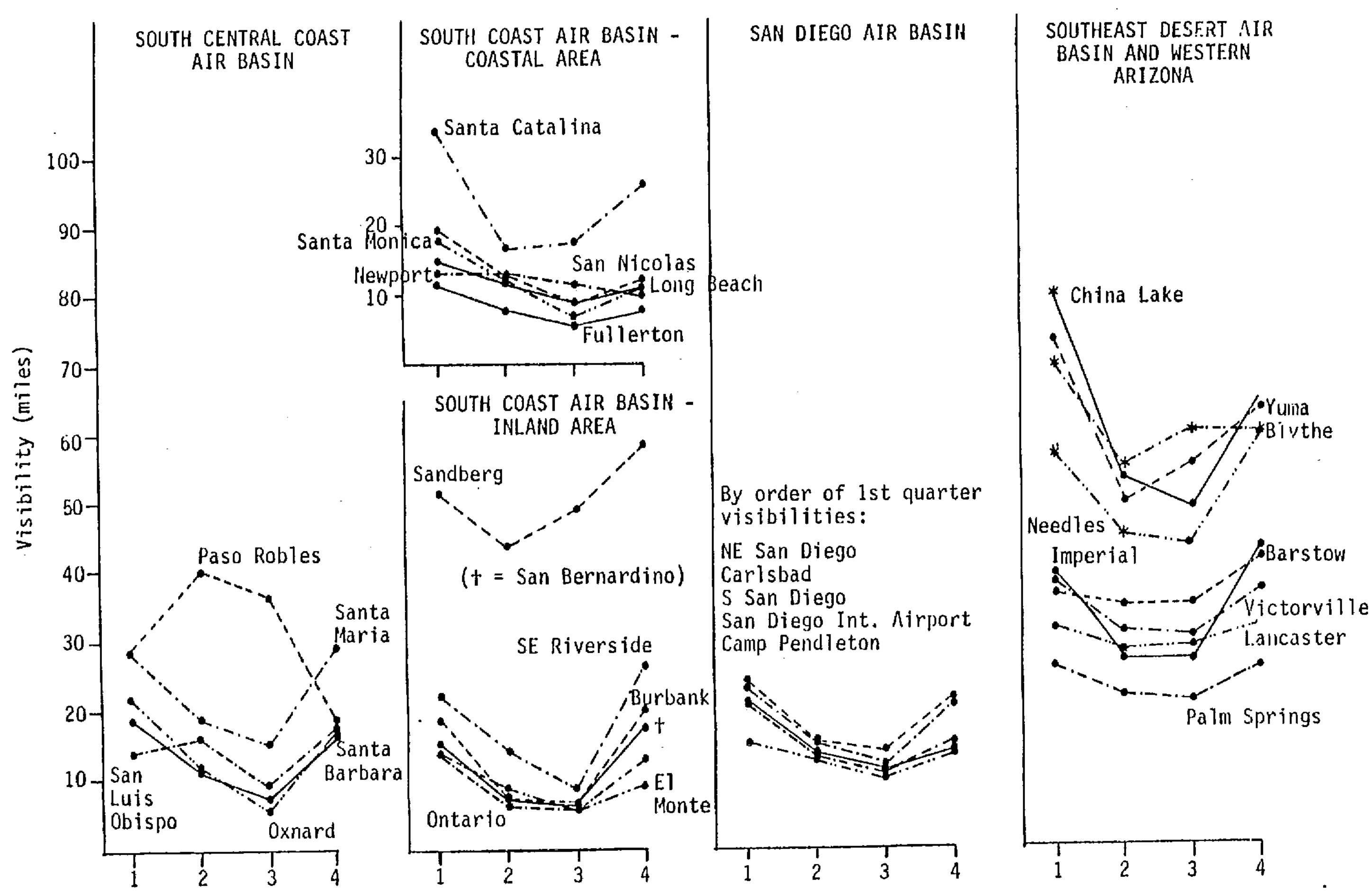


Figure 4.1b Central California

Figure 4.1 Seasonal patterns in California visibility, median 1:00 PM values, 1974-1976 (continued).



Note: Asterisks denote points based on uncertain non-linear extrapolation of frequency distributions.

Figure 4.1c Southern California

Figure 4.1 Seasonal patterns in California visibility, median 1:00 PM values, 1974-1976 (continued).

as at some locations in the North Coast and Lake Tahoe Air Basins), except the maximum visibility is usually displaced from the spring to the summer.

Figures 4.2 through 4.5 illustrate the geographical distribution of median visibility for each of the four seasons. Many significant changes in the spatial distribution of visibility are evident from season to season. The most notable seasonal variations involve the two major pockets of poor visibility, the South Coast Air Basin (SCAB) and the San Joaquin Valley (SJV), which exhibit the following seasonal patterns:

- Visibility in the South Coast Air Basin is lowest during the summer quarter, when nearly all the populated regions of the SCAB experience median visibilities less than 7 miles, and the area from El Monte through Ontario to San Bernardino exhibits a median of approximately 5 miles. During the spring quarter most of the central SCAB has a median visibility less than 10 miles, with an area of less than 7 miles visibility occurring around Ontario. Fall median visibility ranges from slightly less than 10 miles in a small central area of the SCAB to more than 25 miles at the northern and eastern fringes of the region. During the winter quarter, visibility is 12-15 miles in the center of the basin and ranges up to 25 miles at the fringes.
- In contrast to the SCAB, the San Joaquin Valley experiences minimal visibility during the fall, when the central/southern parts of the SJV (from Merced to Bakersfield) exhibit median visibilities less 7 miles, and an area of less than 10 miles visibility extends northward into the southern Sacramento Valley. During the winter, visibility is less than 15 miles in nearly all of the SJV and the southern Sacramento Valley, with a pocket of less than 10 miles occurring south of Fresno (the Visalia, Lemoore area). Summertime median visibility is slightly less than 15 miles in the central/southern SJV and between 15 and 25 miles through most of the remaining SJV. Springtime median visibility is 15-25 miles nearly throughout the SJV.

4.2 ANALYSIS OF SEASONAL PATTERNS

To help reveal some of the causes for the seasonal patterns in visibility, we have stratified the seasonal visibility data by meteorology and have compiled data on seasonal variations in aerosol concentrations. Figure 4.6 illustrates quarterly values of median 1:00 PM visibilities stratified according to meteorological Class III (data without fog, precipitation, or blowing dust/snow; with wind speed less than 12 knots; and with relative humidity between 40 and 70%). Only those visibility sites with computerized

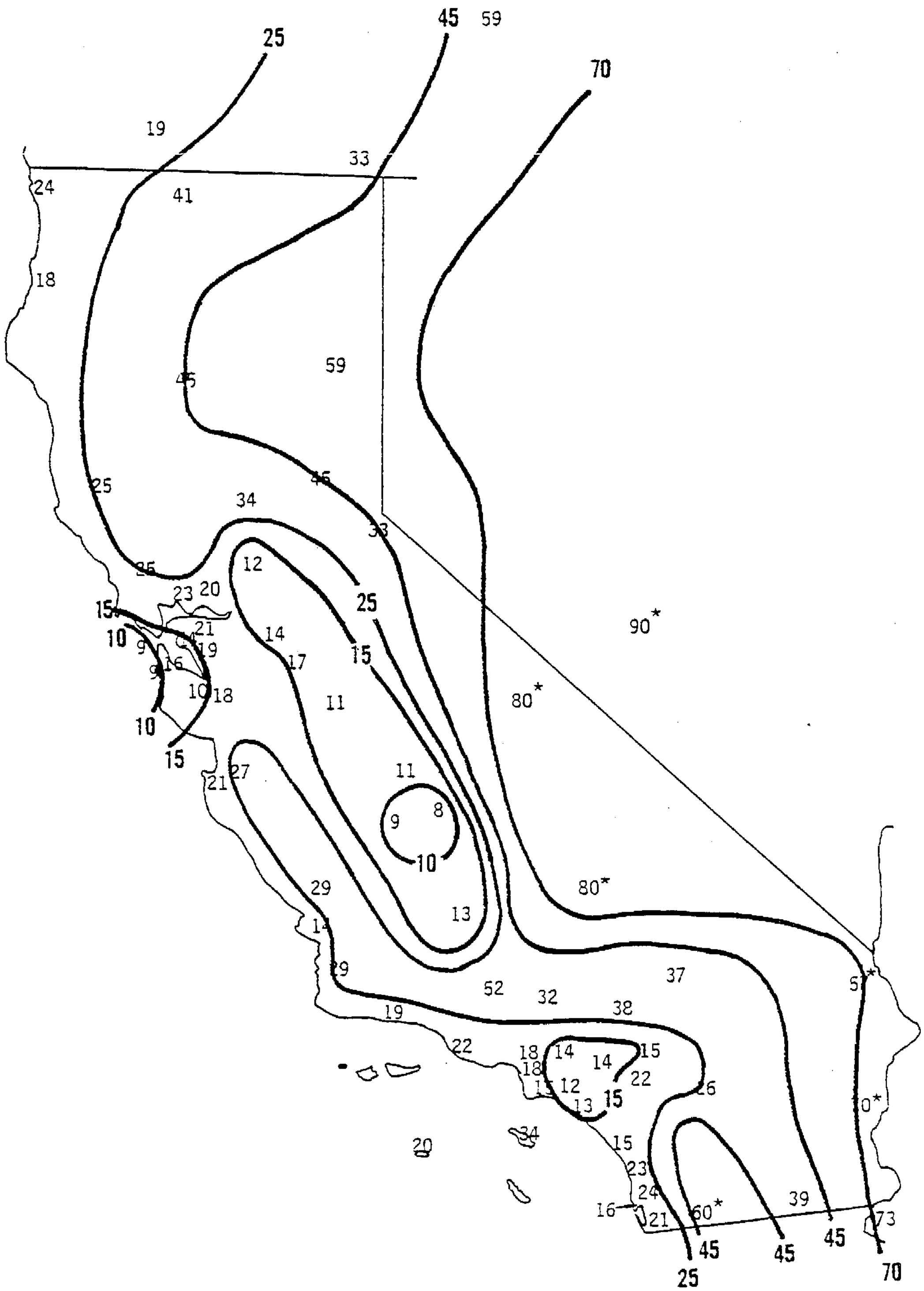


Figure 4.2 Winter (Jan-Mar) median 1 PM visibilities and visibility isopleths for California, all values expressed in miles.

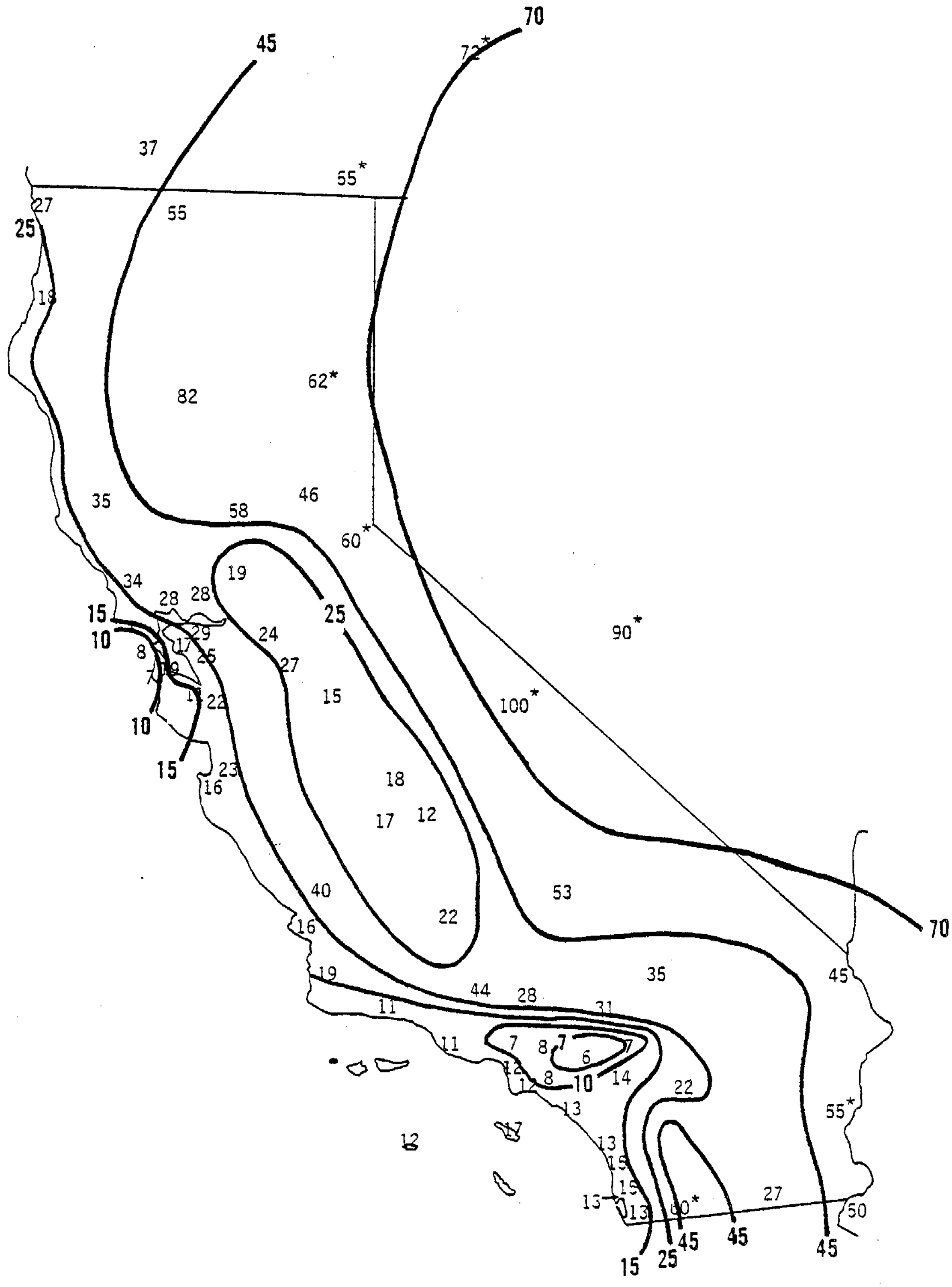


Figure 4.3 Spring (Apr-Jun) median 1 PM visibilities and visibility isopleths for California, all values expressed in miles.

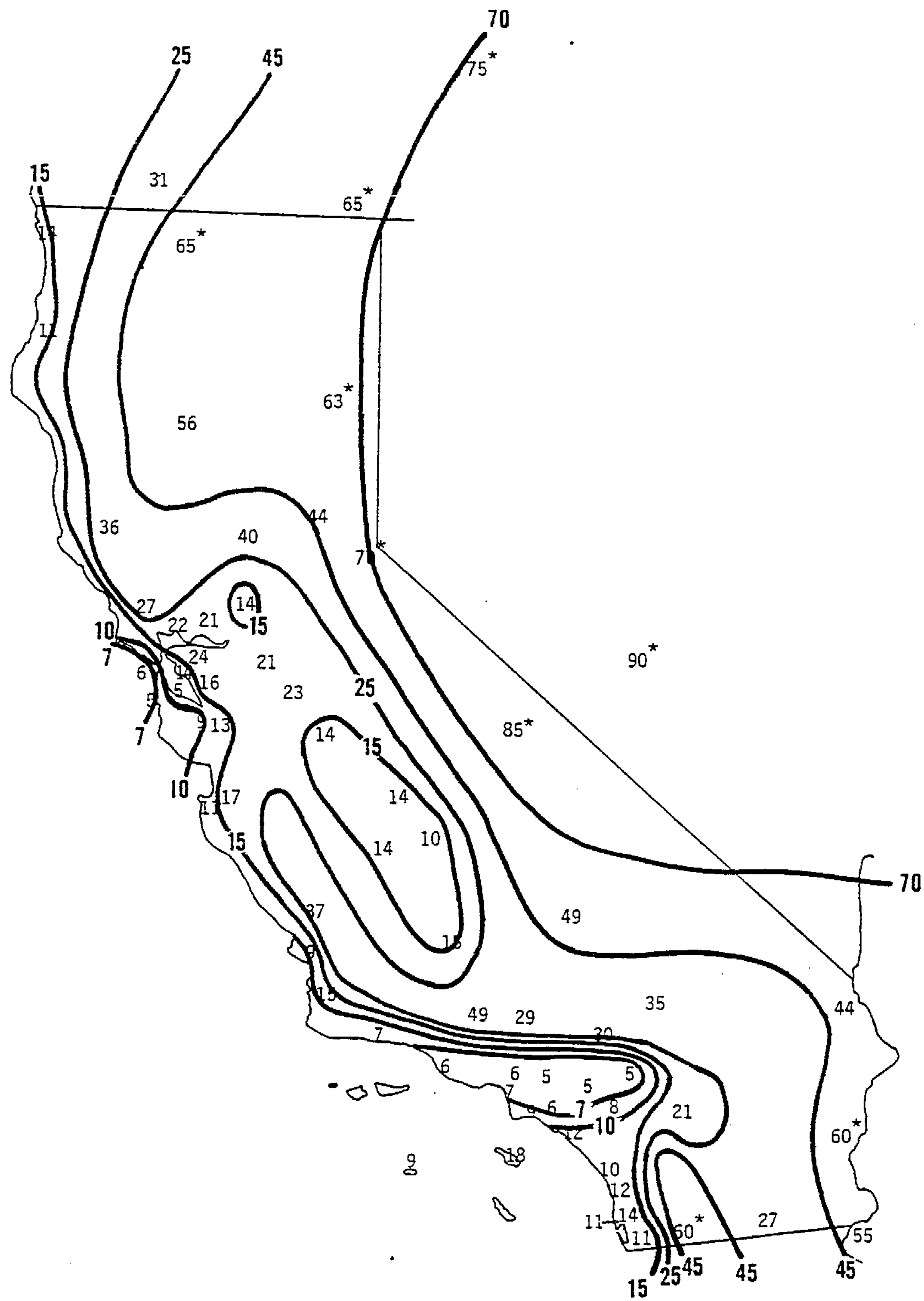


Figure 4.4 Summer (Jul-Sept) median 1 PM visibilities and visibility isopleths for California, all values expressed in miles.

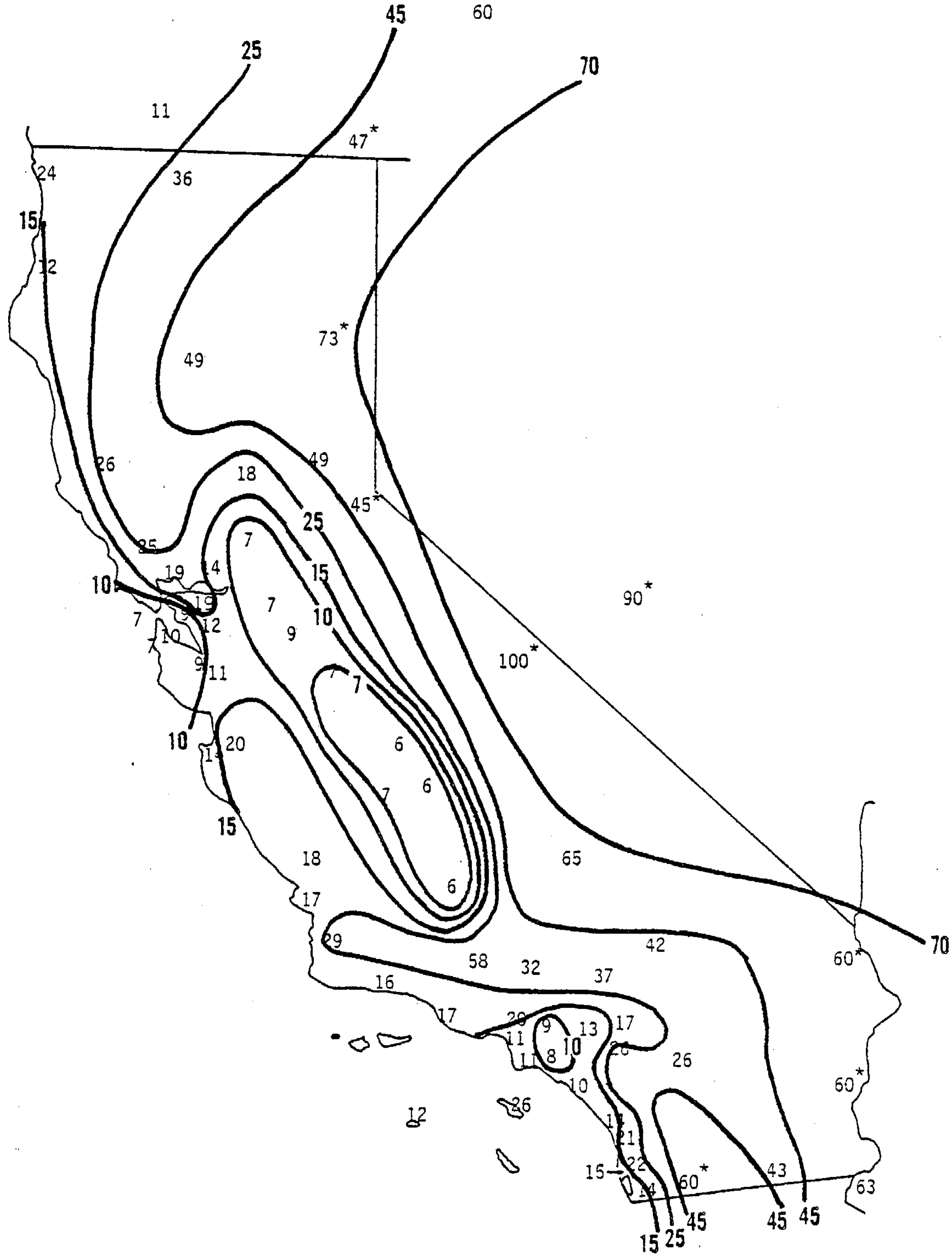


Figure 4.5 Fall (Oct-Dec) median 1 PM visibilities and visibility isopleths for California, all values expressed in miles.

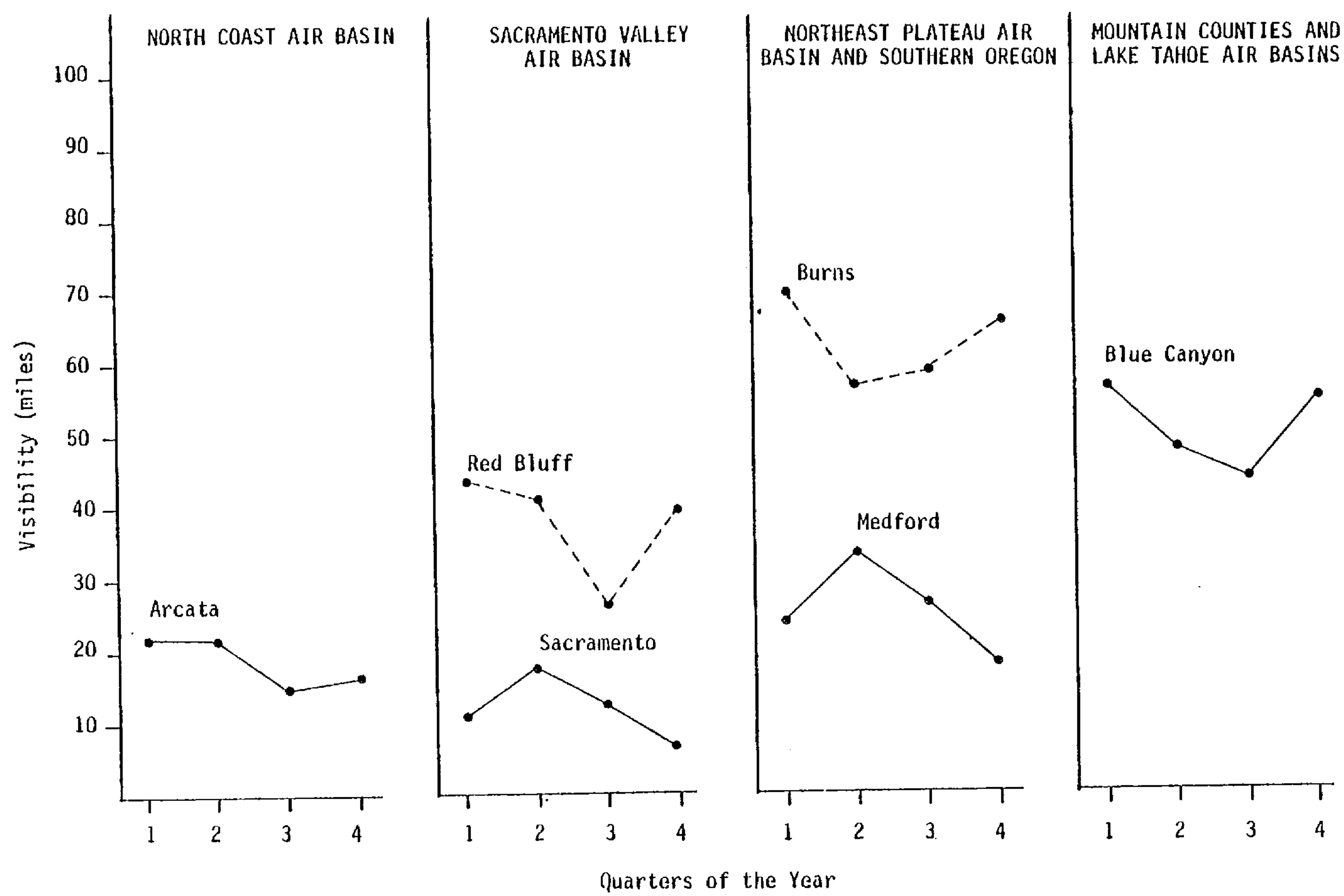


Figure 4.6a Northern California

Figure 4.6 Weather-sorted seasonal patterns in California visibility, median 1:00 PM values for meteorological Class III, 1974-1976.

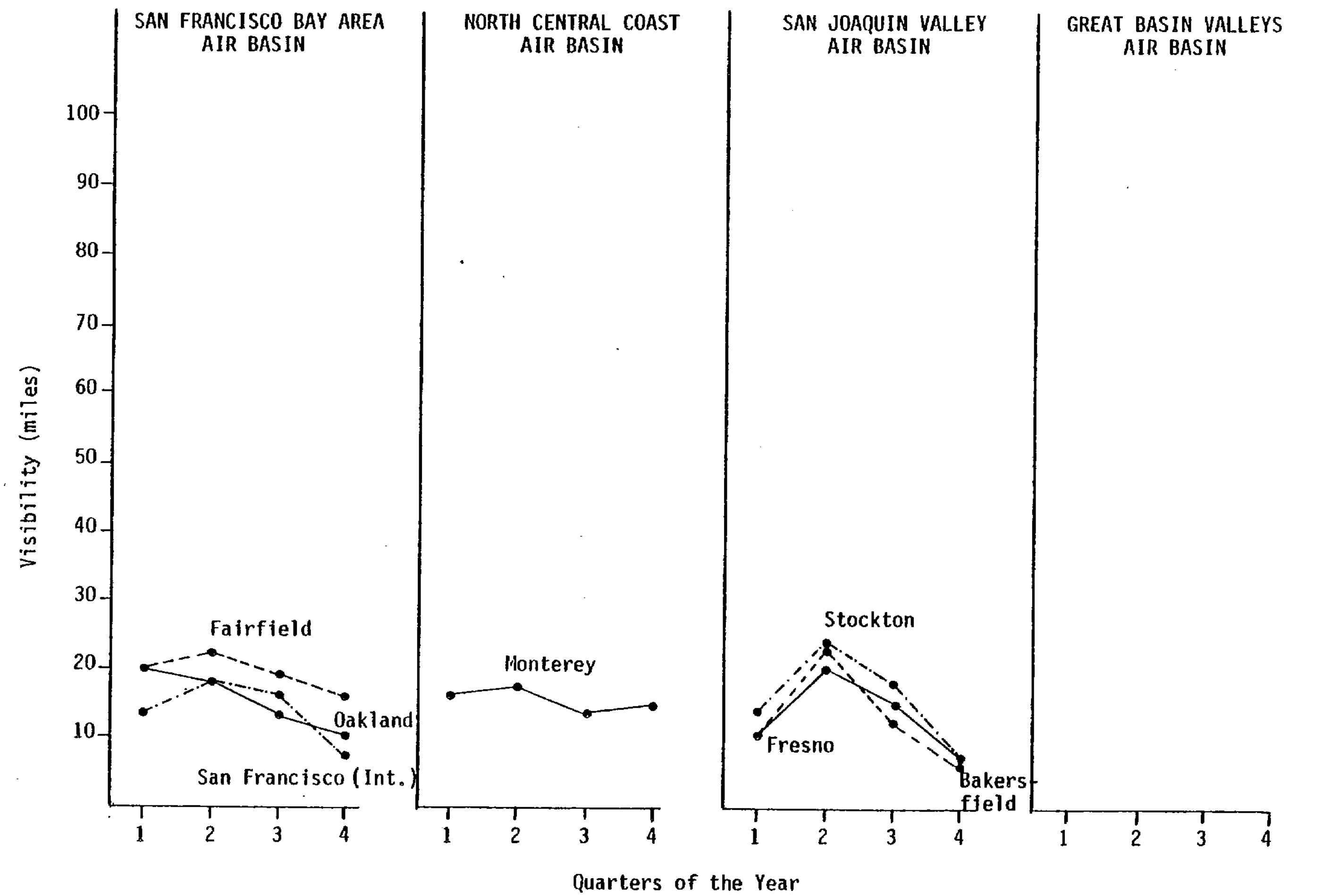


Figure 4.6b Central California

Figure 4.6 Weather-sorted seasonal patterns in California visibility, median 1:00 PM values for meteorological Class III, 1974-1976 (continued).

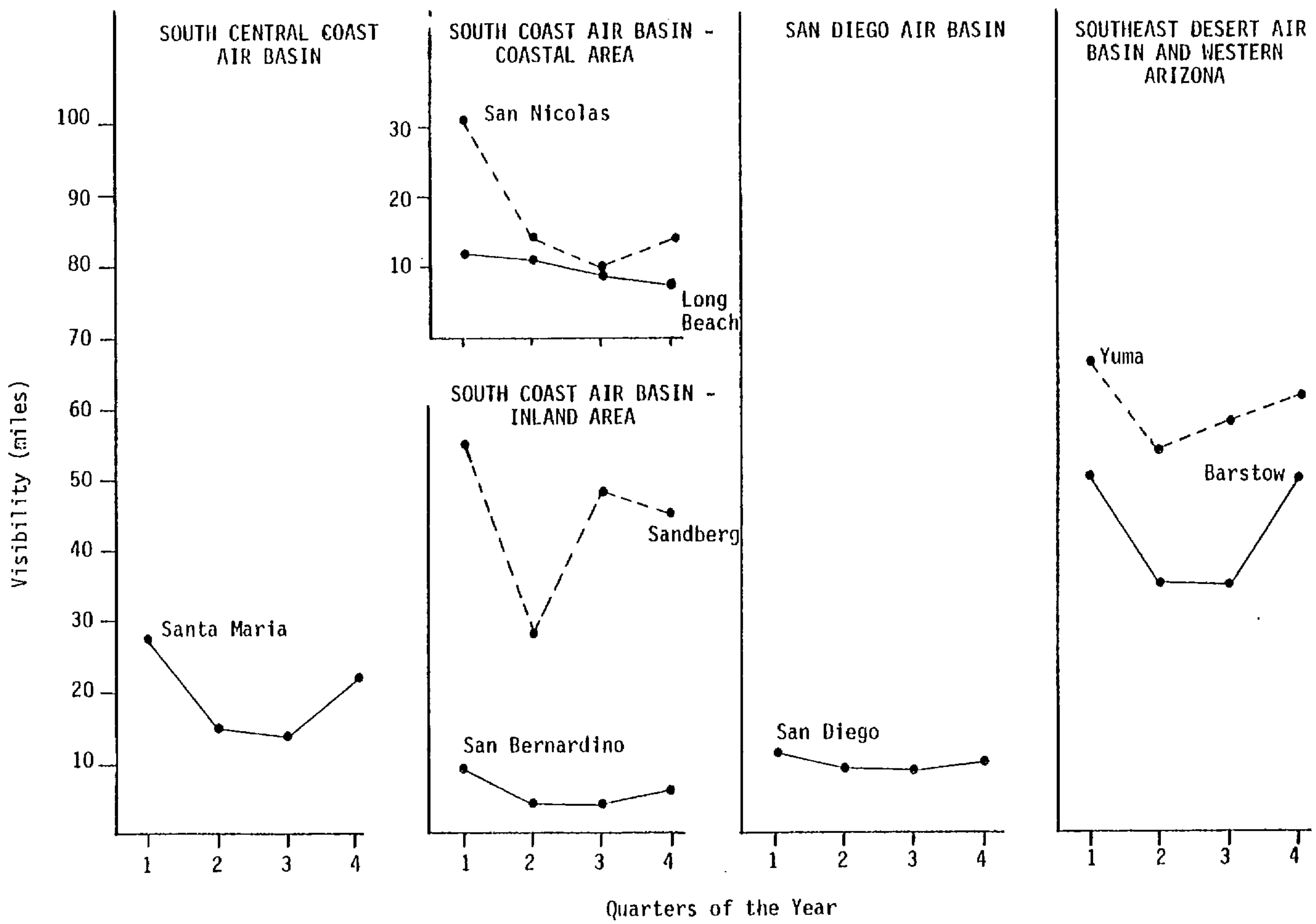


Figure 4.6c Southern California

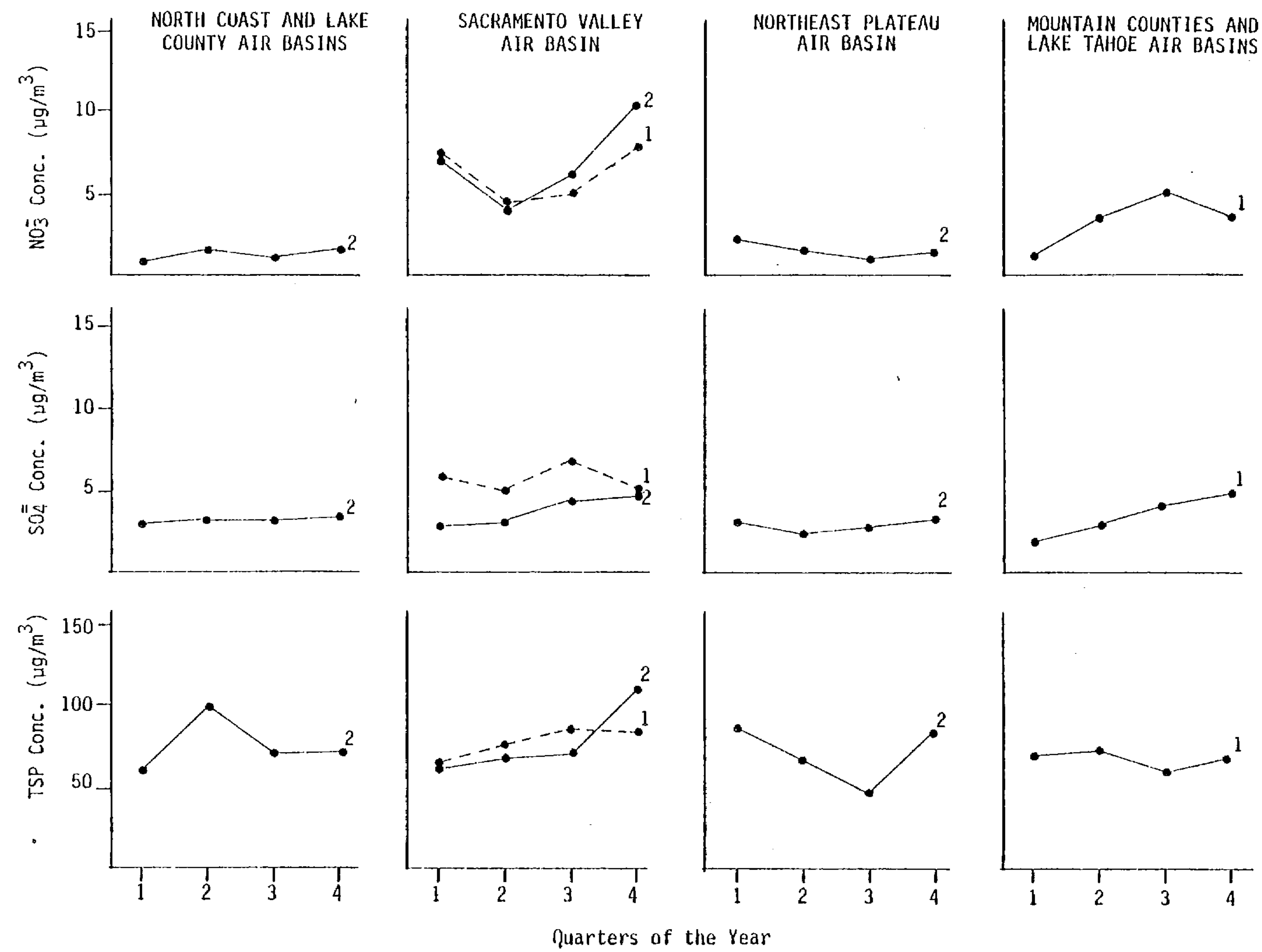
Figure 4.6 Weather-sorted seasonal patterns in California visibility, median 1:00 PM values for meteorological Class III, 1974-1976 (continued).

records are included in Figure 4.6. Figure 4.7 presents quarterly TSP, sulfate, and nitrate concentrations averaged over all NASN sites in each air basin for 1972-1974 and all state/local sites in each air basin for April 1976 - March 1977. It should be noted that the quarterly aerosol data are not extremely robust because of the intermittent schedule for Hi-Vol sampling. Each NASN site yields about 20 days per quarter for the entire three years 1972-1974, and each state/local site has about 15 days per quarter during April 1976 - March 1977. Despite their non-robust nature, the NASN and state/local data usually agree fairly well as to seasonal patterns, and these data sets probably do give a reasonable indication of seasonal variations in aerosol concentrations.

Scrutiny of Figures 4.6 and 4.7 leads to the following conclusions regarding causes of seasonal visibility patterns in various parts of California:

- The severe fall (and winter) minimum in median visibility that occurs within the San Joaquin Valley and southern Sacramento Valley appears to be basically related to air quality variations rather than purely natural factors (e.g. fog, precipitation, or natural haze). Sulfate and nitrate concentrations display a distinct maximum during the fall and winter (see Figure 4.7), and the meteorologically sorted visibility data exhibit an even more pronounced fall/winter minimum than do the raw data (compare Figures 4.1 and 4.6). Higher relative humidity and more stagnant air (NOAA 1977) -- both of which should promote greater sulfate and nitrate concentrations -- are probably the fundamental reasons for the worse air quality and visibility during the fall and winter. Smoke from the burning of rice straw in the southern Sacramento Valley during the 4th quarter (ARB 1978) may also contribute somewhat to the fall minimum in visibility.

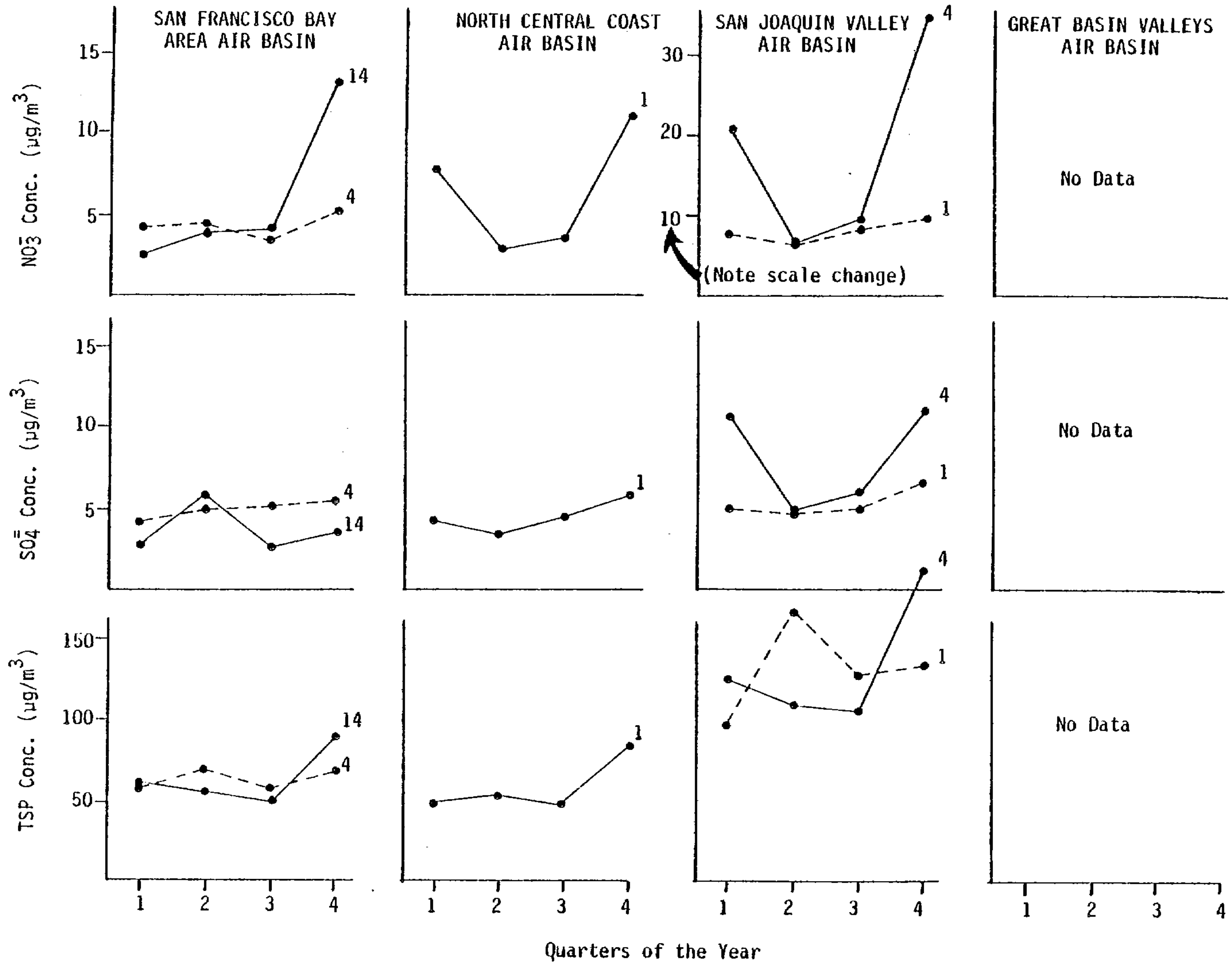
- The severe summer (and spring) minimum in visibility within the South Coast Air Basin appears mostly due to air quality variations, especially to high summertime sulfate concentrations (see Figure 4.7). More intense sunshine, stronger inversion ceilings, and greater inland penetrations of moist air all serve to increase sulfates and other photochemical aerosols during the summer in Los Angeles. The summer/spring minimum in visibility, however, may also be partly due to the purely natural factor of deeper penetration by sea haze; this possibility is suggested by two observations: (1) that the meteorologically sorted data show a less pronounced seasonal pattern than the raw data, and (2) that other, less polluted, coastal areas of southern/central California also exhibit a distinct summer/spring minimum in visibility.



Note: Solid line represents state/local data for April 1976 - March 1977; dashed line represents NASN data for 1972-1974. The numbers to the right of the lines indicate the number of sites in each air basin over which the quarterly data are averaged.

Figure 4.7a Northern California

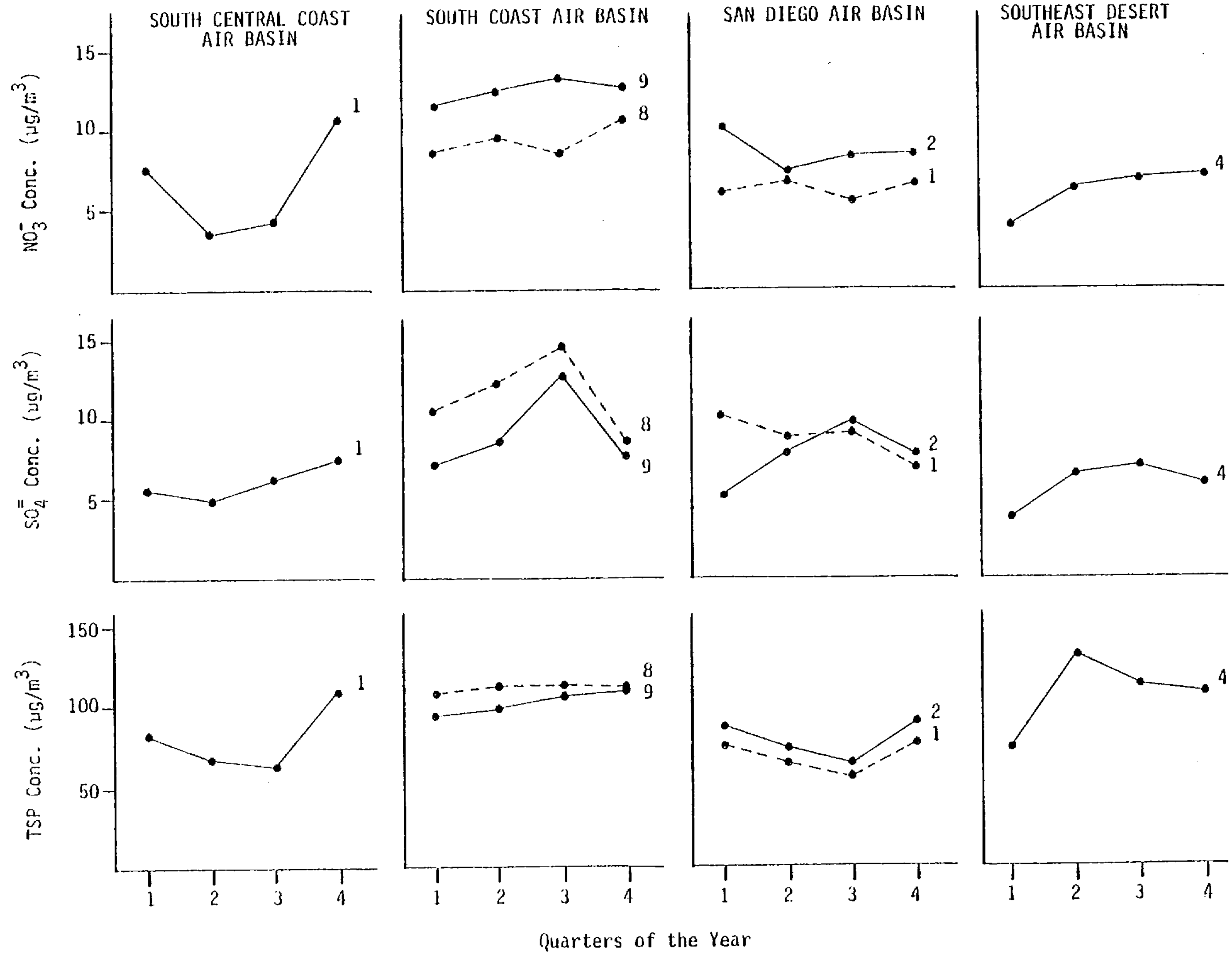
Figure 4.7 Seasonal patterns in TSP, sulfate, and nitrate concentrations.



Note: Solid line represents state/local data for April 1976 - March 1977; dashed line represents NASN data for 1972-1974. The numbers to the right of the lines indicate the number of sites in each air basin over which the quarterly data are averaged.

Figure 4.7b Central California

Figure 4.7 Seasonal patterns in TSP, sulfate, and nitrate concentrations (continued).



Note: Solid line represents state/local data for April 1976 - March 1977; dashed line represents NASN data for 1972-1974. The numbers to the right of the lines indicate the number of sites in each air basin over which the quarterly data are averaged.

Figure 4.7c Southern California

Figure 4.7 Seasonal patterns in TSP, sulfate, and nitrate concentrations (continued).

- Because the meteorologically sorted data and the raw data in the Southeast Desert Air Basin both exhibit a spring/summer minimum in visibility, it is likely that this minimum is due to air quality variations. One possible explanation for the seasonal pattern is penetration of polluted air from the South Coast Air Basin during the spring and summer; the seasonal pattern in sulfate concentrations (see Figure 4.7) is consistent with this explanation. Suspended dust might also contribute somewhat to the seasonal visibility patterns in the Southeast Desert; as suggested by the spring/summer maxima in TSP concentrations (see Figure 4.7) and wind speeds (NOAA 1977), suspended dust concentrations are apparently greatest during the spring and summer quarters.

- The fall visibility minimum that occurs in the San Francisco Bay Area seems to represent air quality variations rather than purely natural factors. This conclusion is indicated by the fall maximum in nitrates (as well as TSP), and by the fact that the meteorologically sorted visibility data display the same fall minimum as the raw data. The cause of poor air quality and visibility during the fall is most likely the greater frequency of stagnation (i.e. lower wind speeds) during that season (NOAA 1977). The winter visibility minimum in San Francisco, on the other hand, seems related to purely natural factors (e.g. fog and precipitation), because the winter visibility minimum is not reflected in the aerosol concentrations, and because the winter minimum tends to be eliminated by meteorological stratification of the data.

- The occurrence of minimum visibility during the spring and summer in the North Central Coast, South Central Coast, and San Diego Air Basins is probably related, in great part, to natural phenomena such as fog and sea haze. This conclusion is suggested by the lack of a close correspondence between minimum visibility and maximal aerosol concentrations, and by the tendency for the spring/summer minimum to be weakened in the meteorologically stratified data.

- The occurrence of minimum visibility during the fall and winter in the Northeast Plateau, Mountain Counties, Lake Tahoe, and northern Sacramento Valley Air Basins also seems to be essentially due to natural phenomena. A consistent correspondence is lacking between visibility patterns and aerosol patterns, and meteorological stratification actually leads to a fall/winter <u>maximum</u> in visibility at most locations in these air basins.

In summary, it should be remarked that a fundamental thread runs through the above discussions. At those locations where man-made visibility impacts are most severe, i.e. the San Joaquin Valley and South Coast Air Basins, the seasonal visibility patterns appear to be closely related to seasonal air quality variations (especially variations in sulfate and nitrate).

At those locations with lesser man-made impacts, i.e. the smaller coastal cities and northeastern California, the seasonal visibility patterns appear to be more closely tied to natural factors.

5.0 DIURNAL PATTERNS OF VISIBILITY

The geographical and seasonal visibility patterns discussed in the previous two chapters were based on data for a single hour each day, the visual range observations at 1:00 PM PST. The present chapter examines the variation of visibility with time of day. Section 5.1 presents and analyzes diurnal visibility patterns based on all data, with no sorting for meteorology. Section 5.2 discusses meteorologically stratified diurnal patterns in visibility.

5.1 DIURNAL PATTERNS WITH NO METEOROLOGICAL STRATIFICATION

This section analyzes diurnal visibility patterns using all computerized data for daytime hours during the years 1974 to 1976. The computerized weather records contain data for four daytime hours: 7 AM, 10 AM, 1 PM, and 4 PM PST. The analysis is restricted to daytime hours and to sites with computerized data for reasons discussed in Section 2.1.

5.1.1 Description of Diurnal Patterns

Figure 5.1 illustrates diurnal patterns in median visibility for 1974-1976 at study sites with computerized data. Figure 5.1a, 5.1b, and 5.1c are for northern, central, and southern California, respectively. The figures are organized by air basin, proceeding from western to eastern regions across the page. As done everywhere in this report, asterisks are used to denote median visibilities based on uncertain extrapolation of the cumulative frequency distribution.

As evidenced by Figure 5.1, with the exception of the far-inland/desert sites, basically all locations display a pattern of increasing visibility during the course of the day, with visual range about 20 to 60% higher at 4 PM than it is at 7 AM. At the far-inland/desert sites (i.e. Burns, Bishop, Tonopah, China Lake, and Yuma), visibility stays about constant or decreases slightly during the day.

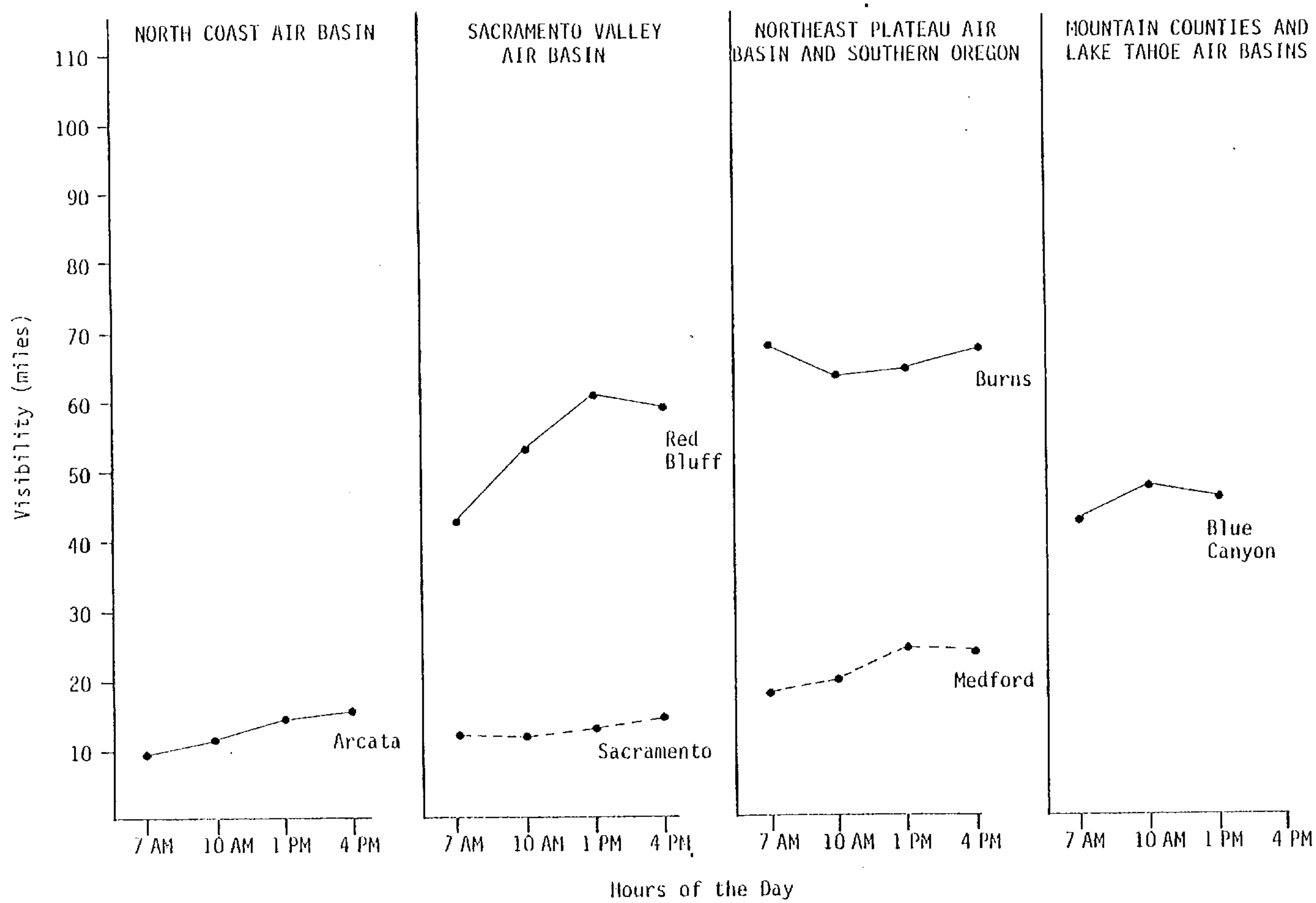


Figure 5.1a Northern California

Figure 5.1 Diurnal patterns in California visibility, median values based on all data for 1974-1976.

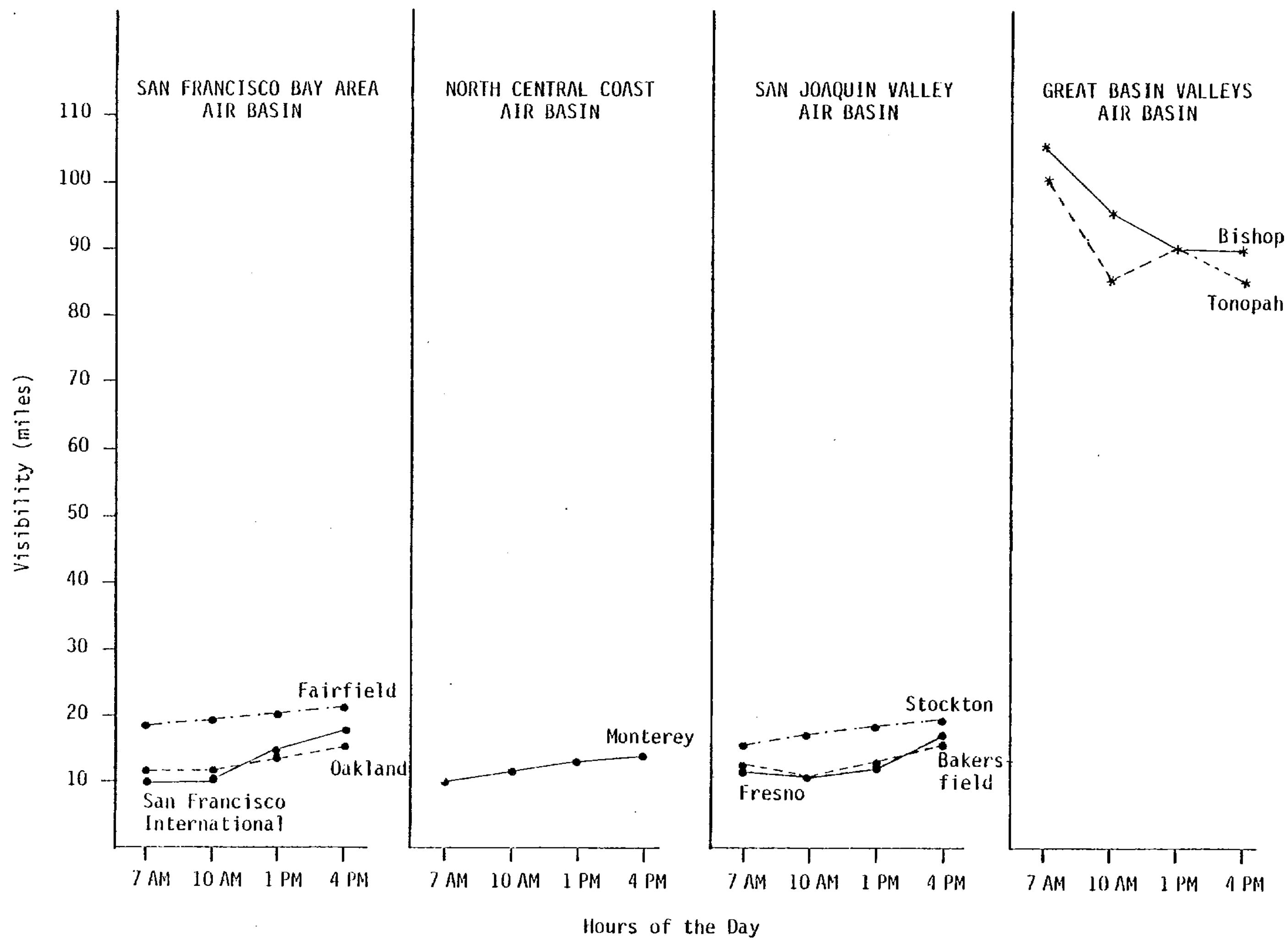


Figure 5.1b Central California

Figure 5.1 Diurnal patterns in California visibility, median values based on all data for 1974-1976 (continued).

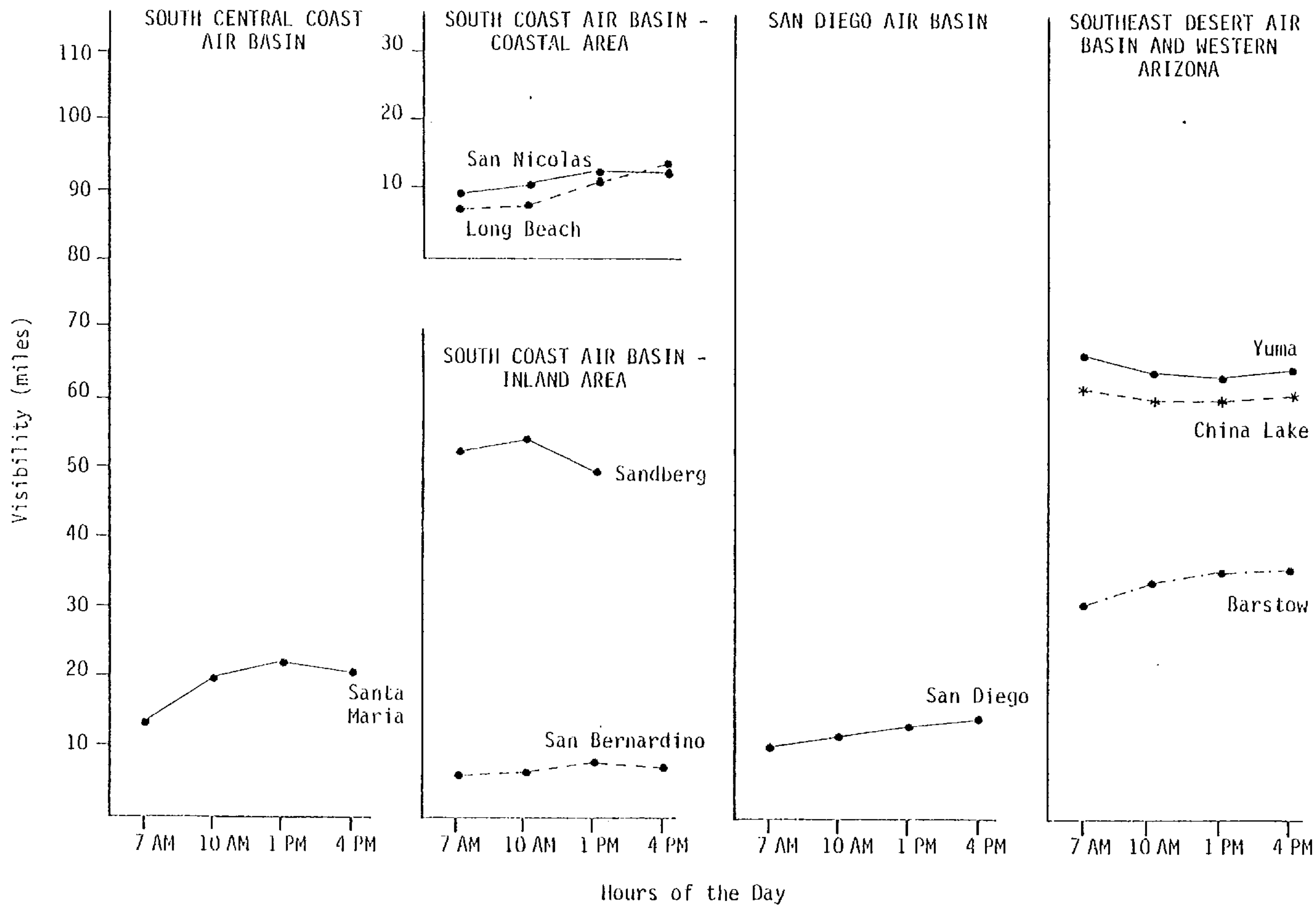


Figure 5.1c Southern California

Figure 5.1 Diurnal patterns in California visibility, median values based on all data for 1974-1976 (continued).

5.1.2 Explanation of Diurnal Patterns

In order to help explain the diurnal patterns in visibility, it would be useful to examine diurnal patterns of aerosol concentrations. Unfortunately, very little data are available on the diurnal variation of particulate concentrations. The ACHEX Study (Hidy et al. 1974) does provide some such data for a few smog-season days in the South Coast Air Basin. The ACHEX data indicate that ambient particulate levels (both total aerosol mass and submicron aerosol mass) in the SCAB tend to peak around 11 AM to noon. Nitrate concentrations peak slightly earlier (around 9-10 AM), while sulfate concentrations peak slightly later (around 2-3 PM). Although it is difficult to generalize based on a few days of data for a single season in a single air basin, it should be noted that the occurrence of peak aerosol concentrations at mid-day is physically reasonable. Primary particulate emissions should increase during the day due to greater human activity levels (traffic, construction, industry, and agriculture); production of secondary aerosols should increase during the day due to the increased photochemical reactivity of the atmosphere. According to the ACHEX results, greater particulate emissions and secondary aerosol production during the day apparently more than counterbalance increasing ventilation rates (higher mixing heights and wind speeds) during the day, at least up to the noontime hour.

If we accept the above (somewhat qualitative) argument that aerosol concentrations tend to peak around mid-day, we conclude that the diurnal variations in ambient aerosol levels do <u>not</u> explain the diurnal variations in visibility (which, except for the far inland/desert locations, tend to increase during the day after a 7 AM minimum). What then is the cause of the observed diurnal visibility patterns? The answer would appear to be relative humidity. As illustrated in Figure 5.2, all types of location within California -- coastal sites, inland valley sites, and far-inland mountain/desert sites -- exhibit a pronounced diurnal pattern in relative humidity; relative humidity tends to decrease during the day, especially from 7 AM to the early afternoon. The increase in visibility during the day at most locations is probably caused by the decrease in water associated with the aerosol, what the layman might call "burning-off" of fog and haze

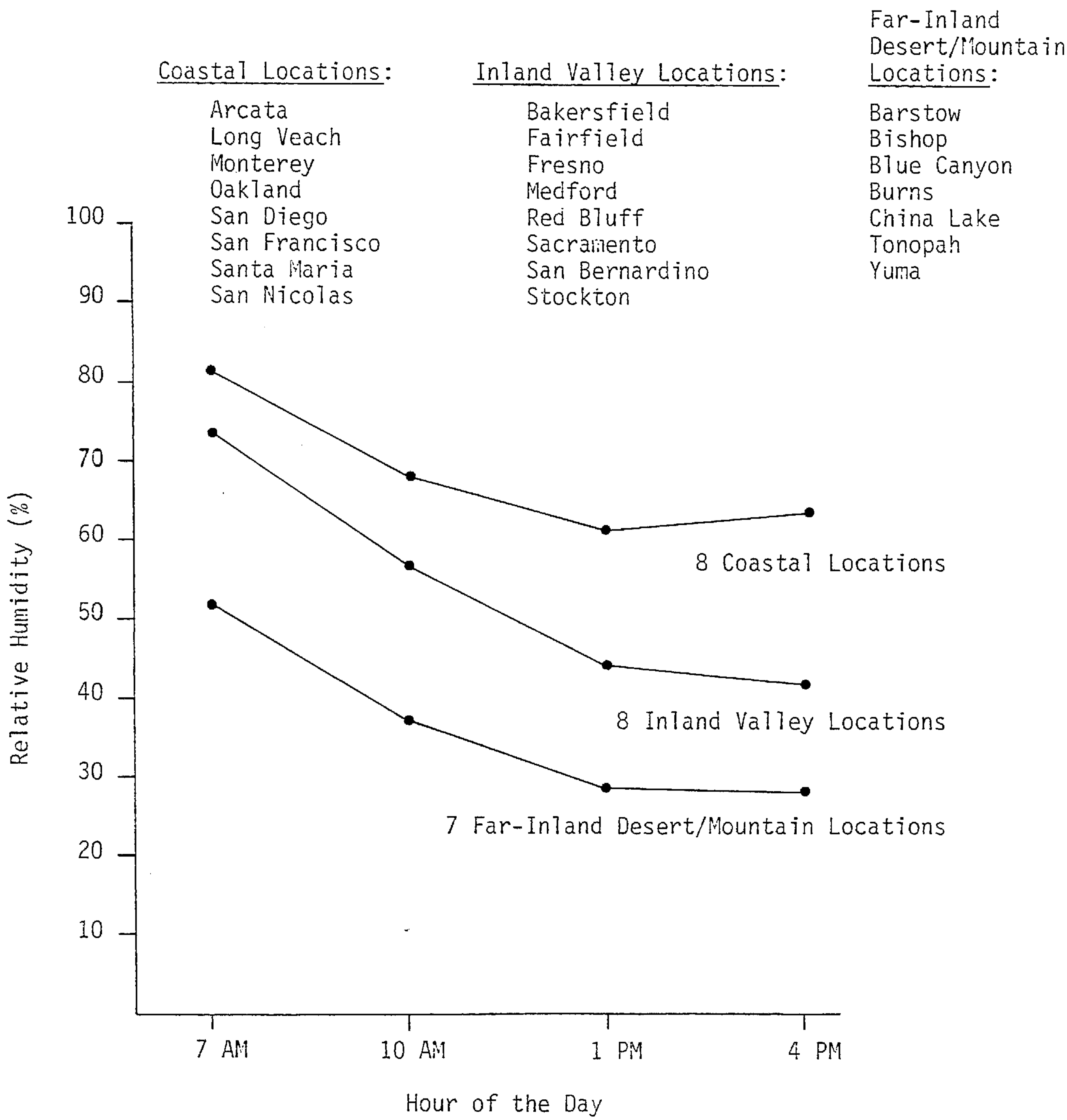


Figure 5.2 Diurnal pattern of relative humidity averaged over various types of location within California, 1974-1976.

by the sun. That natural factors, such as relative humidity, cause the observed diurnal pattern in visibility is also suggested by the results in Section 5.2, where we find that the meteorologically stratified visibility data show an opposite diurnal pattern (maximal visibility at 7 AM with minimal visibility in the early afternoon).

The reason why the far-inland/desert sites do not exhibit the typical pattern of increasing visibility during the day is that, although relative humidity decreases during the day at the desert sites, it starts at a lower level. It is well known that the effects of relative humidity on light-scattering by aerosols are much more significant at higher values of relative humidity (Covert 1974; Hidy et al. 1974). With the relative humidity effect reduced in the desert by the generally dry conditions, other factors (probably aerosol concentrations) become more significant to the diurnal visibility patterns.

5.1.3 Time of Minimum Visibility

To gain further insights concerning the diurnal behavior of visibility, it is interesting to examine the average time of occurrence of minimum visibility. Figure 5.3 illustrates the geographical pattern of the average time for minimum visibility (based on all data for the four daytime hours during 1974-1976). An obvious coast-to-inland gradient appears in the data. The coastal sites experience minimum visibility at around 9 to 10 AM on the average, while the far-inland/desert sites undergo minimum visibility at around 11 to 12 AM on the average. The explanation for this spatial pattern is that relative humidity effects -- which tend to produce minimum visibility early in the morning (i.e. at the 7 AM observation) -- are most important along the coast. As one proceeds inland, the diurnal patterns of aerosol concentrations become of greater significance as the relative humidity effects diminish in significance.

Scrutiny of the data in Figure 5.3 indicates that the spatial gradients in average time of minimum visibility are slightly more intense in the South Coast and San Francisco Bay Area Air Basins than at other coastal locations. This may reflect pollution transport within the Los Angeles and San Francisco air basins. The transport of man-made photochemical aerosols under the daytime sea-breeze should lead to minimum visibility during the afternoon on

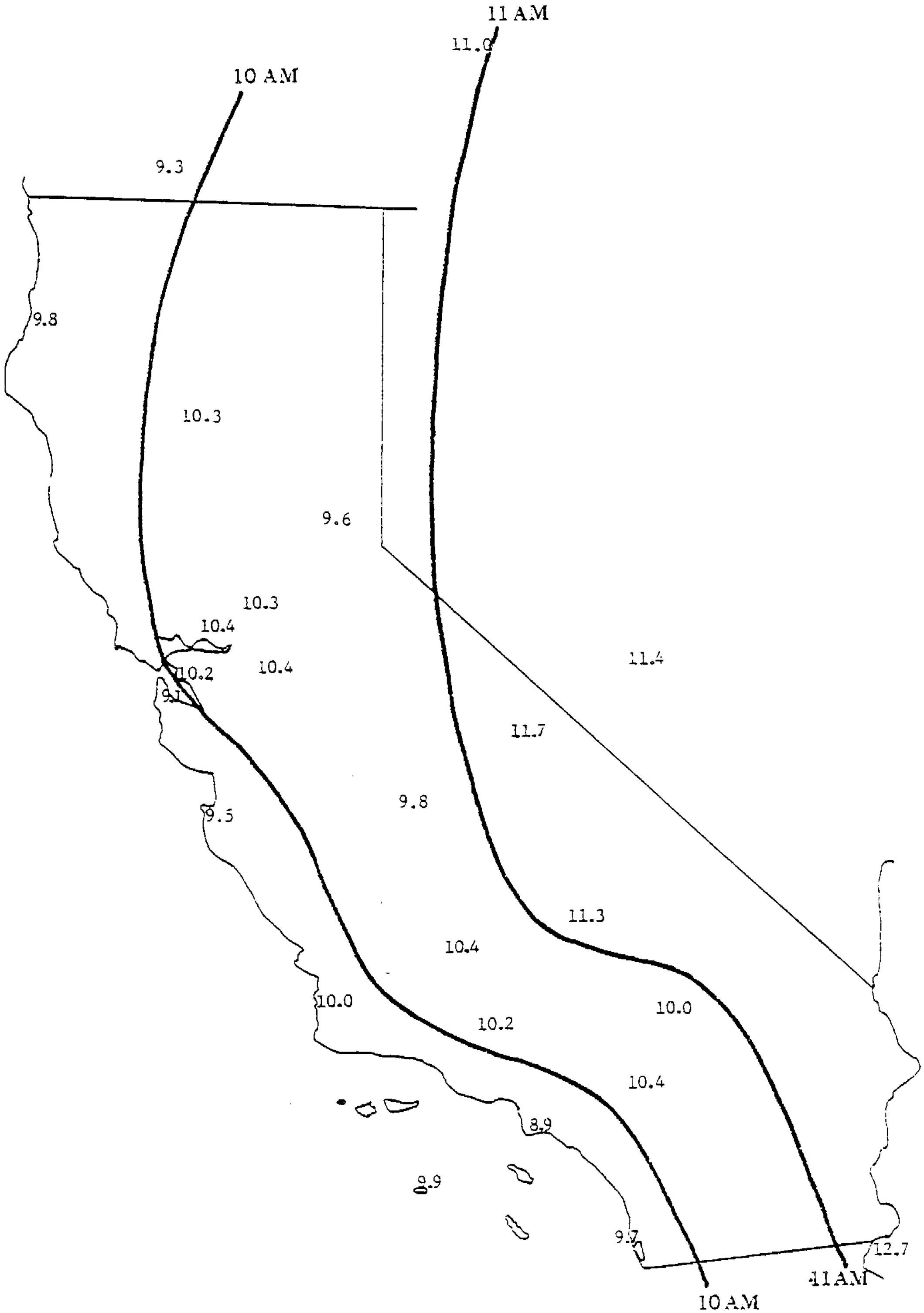


Figure 5.3 Spatial pattern of the average time for minimum visibility, based on all data for the four daytime hours during 1974-1976.

some days at the inland locations within those air basins; this effect would produce a later-than-normal average time of minimum visibility for inland locations within these air basins.

5.1.4 Representativeness of 1:00 PM Visibility Data

Because all of our analyses of geographical visibility patterns (Chapter 3) and seasonal visibility patterns (Chapter 4) are based solely on the 1:00 PM visual range observations, it is worthwhile to investigate whether the median 1:00 PM visibilities are representative of median visibilities based on all four daytime observations. A sensitivity analysis addressing this question for the 1974-1976 data is presented in Table 5.1. Table 5.1 indicates that the relative difference between the 1:00 PM and the 4-hour medians ranges from -7% to +18% and averages +4.5% among the 21 locations. These differences are not very great, and we conclude that the median 1:00 PM visibilities are fairly representative of medians based on all four daytime hours.

5.2 METEOROLOGICALLY STRATIFIED DIURNAL PATTERNS

There are two ways to stratify the diurnal visibility patterns according to meteorology. The first way, method #1, is to use all data for each hour that fall into a given weather class, e.g. our meteorological Class III (data without fog, precipitation, or blowing dust/snow; with wind speed less than 12 knots; and with relative humidity between 40 and 70%). Method #2 is to use only those days when all four hours fall into the same weather class, e.g. meteorological Class III. Both of these methods involve serious fundamental difficulties brought about by the strong diurnal patterns in relative humidity. The problem with the method #1 is that different types of days are often being considered for different hours. For example, the set of days when relative humidity is 40 to 70% at 7 AM is usually very different from the set of days when relative humidity is 40 to 70% at 1 PM or 4 PM; we might be emphasizing days with dry continental air in considering the 7 AM data, while emphasizing days with moist maritime air in considering the 1 PM or 4 PM data. The problem with method #2 is that extremely few days meet the Class III criteria during all four daytime hours; when relative humidity

TABLE 5.1 COMPARISON OF MEDIAN 1:00 PM VISIBILITIES TO MEDIAN 4-HOUR DAYTIME VISIBILITIES, 1974-1976.

AIR BASIN, Site	Median 1:00 PM Visibility (miles)	Median Visibility Based on all 4 Daytime Observations (miles)	Percent Difference of 1:00 PM Value Relative to 4-Hour Value
NORTH COAST			
Arcata	14.8	12.8	+16%
SACRAMENTO VALLEY			
Red Bluff	61.0	53.6	+14%
Sacramento	13.6	13.4	+ 1%
NORTHEAST PLATEAU AND SOUTHERN OREGON			
Burns	59.2[a]	59.5[a]	- 1%
Medford	24.9	22.5	+11%
MOUNTAIN COUNTIES AND LAKE TAHOE			
Blue Canyon	45.9	45.0	+ 2%
SAN FRANCISCO BAY AREA			
Oakland	14.0	13.3	+ 5%
San Francisco Int.	14.7	12.5	+18%
SAN JOAQUIN VALLEY			
Bakersfield	13.5	13.7	- 1%
Fresno	12.7	13.0	- 2%
Stockton	18.0	17.9	+ 1%
GREAT BASIN VALLEYS AND WESTERN NEVADA			
Bishop	62.4[b]	66.0[b]	- 5%
Tonopah	51.1[c]	48.4[c]	+ 6%
SOUTH CENTRAL COAST			
Santa Maria	21.9	20.0	+10%
SOUTH COAST (Coastal Part)			
Long Beach	11.2	9.8	+14%
San Nicolas	12.2	11.3	+ 8%
SOUTH COAST (Inland Part)			
Sandberg	48.8	51.9	- 6%
SAN DIEGO			
San Diego	13.4	12.5	+ 7%

TABLE 5.1 COMPARISON OF MEDIAN 1:00 PM VISIBILITIES TO MEDIAN 4-HOUR DAYTIME VISIBILITIES, 1974-1976 (Continued).

AIR BASIN, Site	Median 1:00 PM Visibility (miles)	Median Visibility Based on all 4 Daytime Observations (miles)	Percent Difference of 1:00 PM Value Relative to 4-Hour Value
SOUTHEAST DESERT AND WESTERN ARIZONA			
Barstow	34.7	33.1	+ 5%
China Lake	46.1[d]	49.8[d]	- 7%
Yuma	59.1	60.5	- 2%

[a] 60th percentile rather than median

[b] 85th percentile rather than median

[c] 90th percentile rather than median

[d] 75th percentile rather than median

is between 40 and 70% at 7 AM it is very unlikely to be in the same range at 4 PM, and vice versa. Since method #2 is eliminated by default (insufficient days meeting the criterion), we have chosen method #1.* The reader should remember, however, the important caveat associated with method #1 when considering the results presented below.

Figure 5.4 presents diurnal visibility patterns for the meteorologically stratified data. Nearly all sites now exhibit a maximum in visibility at 7 AM (in contrast to the 7 AM minimum for the raw data) with minimum visibility usually occurring at 1 PM but sometimes at 10 AM or 4 PM. This result agrees with our earlier discussion concerning the diurnal variation of particulate concentrations (i.e. we expect both primary and secondary aerosol concentrations to peak around mid-day). In the South Coast and San Francisco Air Basins, there is a consistent pattern of minimal visibility occurring later

*Because only method #2 can be used for meteorological stratification in our analysis of the average time when minimum visibility occurs, we have not repeated that analysis using weather-sorted data.

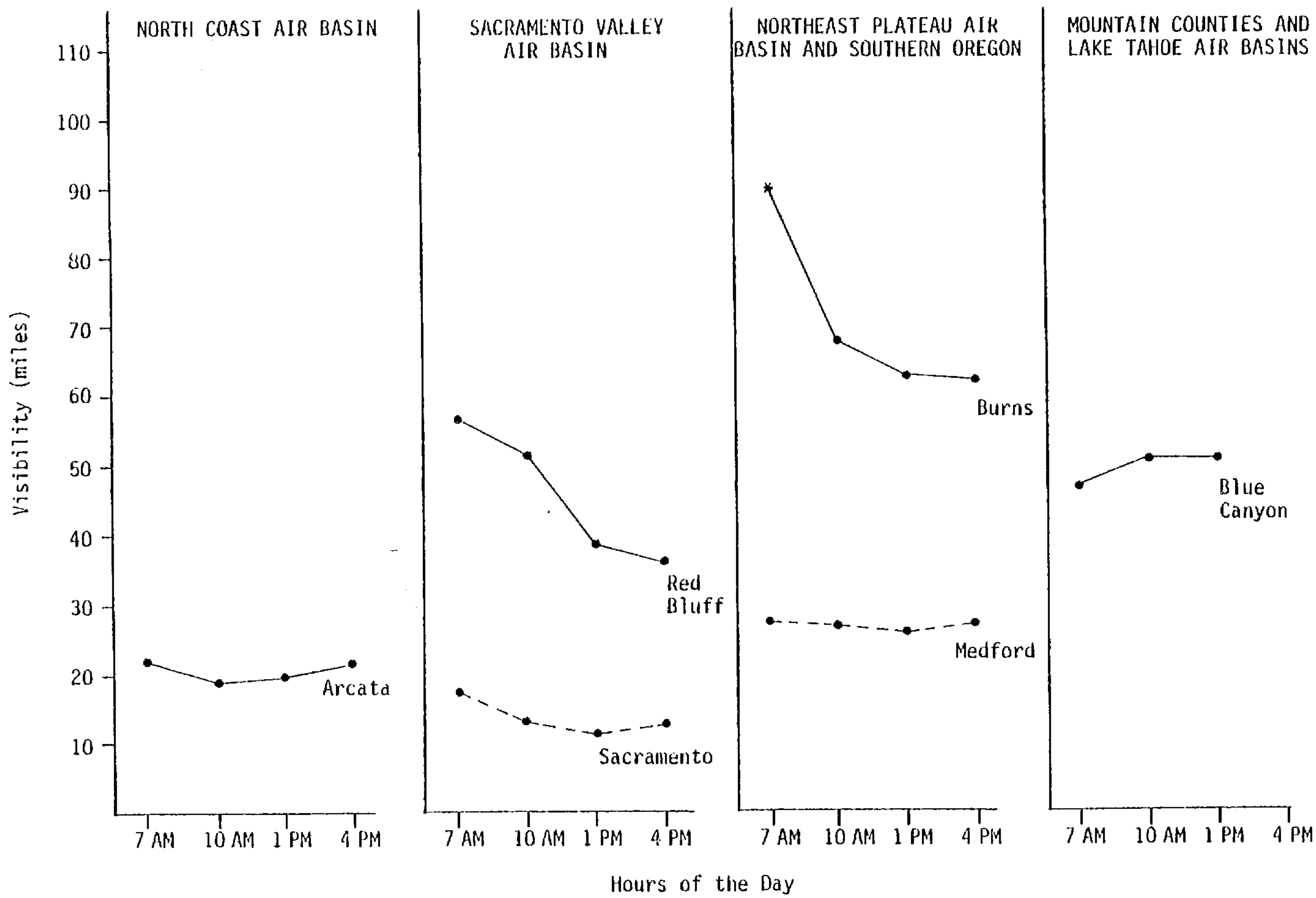


Figure 5.4a Northern California

Figure 5.4 Weather-sorted diurnal patterns in California visibility, median values for meteorological Class III, 1974-1976.

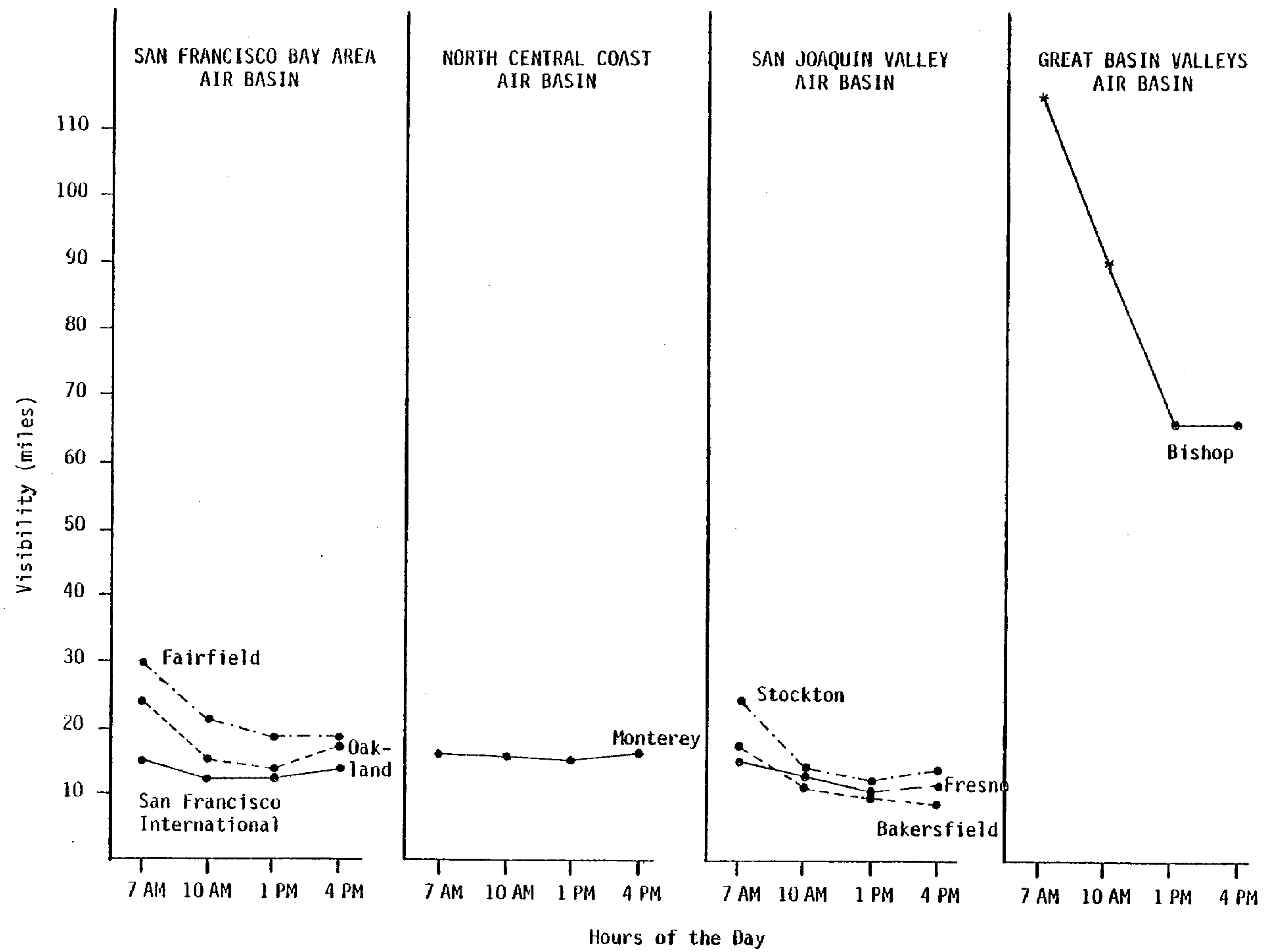


Figure 5.4b Central California

Figure 5.4 Weather-sorted diurnal patterns in California visibility, median values for meteorological Class III, 1974-1976 (continued).

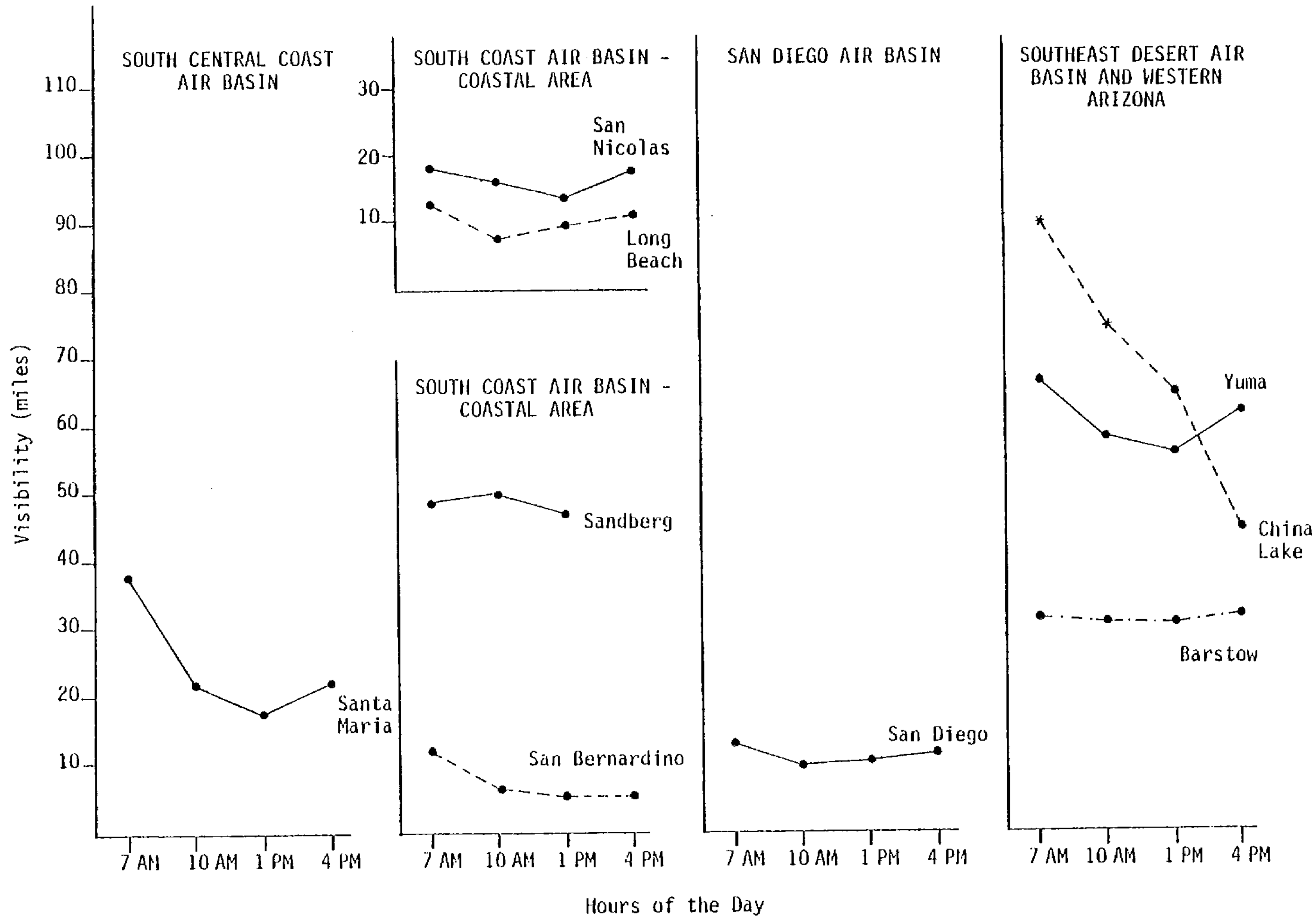


Figure 5.4c Southern California

Figure 5.4 Weather-sorted diurnal patterns in California visibility, median values for meteorological Class III, 1974-1976 (continued).

at the more inland locations; this pattern may represent coast-to-inland transport of pollutant aerosols under the daytime sea breeze. Of course, as noted in the previous paragraph, some of the patterns found in Figure 5.4 may be an artifact of the meteorological stratification procedure.

6.0 VISIBILITY/AEROSOL RELATIONSHIPS

Before strategies can be planned for maintaining or improving visibility in California, the most significant atmospheric components contributing to visibility reduction must be identified. This chapter relates airport visibility measurements to Hi-Vol particulate measurements in order to gain insights regarding the important aerosol components that affect visibility.

6.1 STATISTICAL MODELING APPROACH

Our analysis of visibility/pollutant relationships follows the statistical procedures established by Cass (1979), White and Roberts (1977), and Trijonis and Yuan (1978a, b). Regression equations are developed which relate daytime average visibility to daily averages of total suspended particulate (TSP), sulfates ($SO_4^=$), nitrates (NO_3^-), and relative humidity (RH). The coefficients in these regression equations can be interpreted as estimates of "extinction coefficient per unit mass" for each of the aerosol species. These extinction coefficients allow us to estimate the fraction of haze (or fraction of visibility loss) attributable to each aerosol component. The following sections summarize the statistical techniques and discuss some of the potential limitations in the methods.

6.1.1 Definition of Variables

The data for our study of visibility/aerosol relationships consist of the measurements listed in Table 6.1. Before conducting statistical analyses of the data, however, we perform some simple changes in the forms of the variables. For example, instead of using visual range (V) as the dependent variable, it is convenient to use the extinction coefficient,

$$B = \frac{24.3}{V} , \qquad (6\text{-}1)$$

where the units of B are $[10^4 \text{ meters}]^{-1}$ and the units of V are [miles]. As discussed in Section 1.1, the extinction coefficient is a linear sum of four components: light scattering by gases, light scattering by aerosols, light absorption by gases, and light absorption by aerosols. It is more appropriate

TABLE 6.1 DATA FOR VISIBILITY/AEROSOL STUDIES

	Variable	Units	Averaging Time
V...	visibility or visual range	miles	4 daylight measurements
RH...	relative humidity	percent	4 daylight measurements
TSP...	total suspended particulates	$\mu g/m^3$	24-hour average
$SO_4^=$...	sulfates	$\mu g/m^3$	24-hour average
NO_3^-...	nitrates	$\mu g/m^3$	24-hour average

to use extinction rather than visibility in linear regressions because each of the components of extinction should be directly proportional to aerosol or gas concentrations (assuming other factors such as light wavelength, aerosol size distribution, particle shape, and refractive index remain constant). In most urban or large-scale regional hazes, it is thought that aerosol light scattering tends to dominate over the other contributions to the extinction coefficient.

Slight transformations are also performed on the independent variables. Following White and Roberts (1977) we define

$$S = \text{SULFATE} = 1.3\ SO_4^=$$

and (6-2)

$$N = \text{NITRATE} = 1.3\ NO_3^-$$

in order to account for the mass of cations (presumably ammonium) associated with the measured values of $SO_4^=$ and NO_3^-. The variable,

$$T = \text{TSP} - \text{SULFATE} - \text{NITRATE} = \text{TSP} - S - N \qquad (6\text{-}3)$$

is used to represent the non-sulfate, non-nitrate fraction of TSP.

At three of our study sites data were available for a fourth aerosol parameter, benzene soluble organics (BSOL). Of the 12 regressions (3 sites x 2 subsets of data x 2 regression equations) that were conducted with data including benzene solubles, BSOL was a statistically significant variable in only one case. To simplify this chapter, we have decided to eliminate the BSOL variable completely in the following results and discussions.

6.1.2 Multi-Variate Regression

When several independent variables (S, N, T, and RH) are affecting a dependent variable (B) it is important to perform a multi-variate analysis that can separate out the individual impact of each independent variable, discounting for the simultaneous effects of other independent variables. Uni-variate analyses, based on simple one-on-one relationships, can lead to spurious results because of intercorrelations among the independent variables. For example, in some cases T might be correlated with B only because it is correlated with SULFATE which, in turn, is significantly related to B.

An appropriate tool for multi-variate analysis is multiple regression. Following the procedure of Cass (1979), White and Roberts (1977), and Trijonis and Yuan (1978a, b) we perform multiple linear regressions of the form

$$B = a + b_1 \mathrm{SULFATE} + b_2 \mathrm{NITRATE} + b_3(\mathrm{TSP} - \mathrm{SULFATE} - \mathrm{NITRATE}) + b_4 \mathrm{RH}$$

or

$$B = a + b_1 S + b_2 N + b_3 T + b_4 \mathrm{RH} \quad . \tag{6-4}$$

These regressions are run stepwise, retaining only those terms which are greater than zero at a 95% confidence level. The regression coefficients (b_1, b_2, and b_3) represent the extinction coefficient per unit mass for each aerosol species, in units of $(10^4 \text{ meters})^{-1}/(\mu g/m^3)$.

To facilitate interpretation of the results, we choose to write the results of the linear regressions as

$$B = a' + b_1 S + b_2 N + b_3 T + b_4(\mathrm{RH} - \overline{\mathrm{RH}}) \tag{6-5}$$

where $\overline{\mathrm{RH}}$ = average relative humidity for the location, and $a' = a + b_4\overline{\mathrm{RH}}$. The constant term "a'" represents the extinction coefficient when the three aerosol variables are zero and relative humidity is at its average value.

We also perform regressions which include relative humidity effects in a nonlinear manner. Cass (1979) indicates that light scattering by a submicron, hygroscopic aerosol might be proportional to $(1 - \frac{\mathrm{RH}}{100})^{\alpha}$, where the exponent α is expected to occur in the range -0.67 to -1.0. To account for this type of effect, we attempt regressions of the form

$$B = a + b_1 \frac{\text{SULFATE}}{(1 - \frac{RH}{100})} + b_2 \frac{\text{NITRATE}}{(1 - \frac{RH}{100})} + b_3 \frac{\text{TSP-SULFATE-NITRATE}}{(1 - \frac{RH}{100})} . \qquad (6\text{-}6)$$

For many locations, the constant "a" in Equation (6-6) turns out to be approximately the same as the constant "a'" in Equation (6-5).

6.1.3 Average Extinction Budget

The regression equations can be used to compute the fraction of visibility loss, on the average, that is due to each aerosol species. These calculations are best illustrated by examples.

The linear regression equation for Oakland (for the data set excluding all days with precipitation or fog) results in the formula,

$$B = 0.14 + .12\ \text{SULFATE} + .014\ (\text{TSP - SULFATE - NITRATE}) + .040\ (RH - \overline{RH}), \qquad (6\text{-}7)$$

with a total correlation coefficient of 0.83. The average value for the extinction coefficient at Oakland is $B = 2.18\ [10^4 \text{meters}]^{-1}$, corresponding to a visibility of 11 miles. Using Equation (6-7), the average extinction at Oakland can be disaggregated into components by substituting in average values for the variables. With average values for B, SULFATE, TSP - SULFATE - NITRATE, and RH, Equation (6-7) reduces to

$$2.18 = \underset{\substack{\text{Blue-sky scatter}\\ \text{by air molecules}}}{0.12} + \underset{\substack{\text{Remainder of}\\ \text{constant term}}}{0.02} + \underbrace{.124\ (\overset{\text{Average SULFATE}}{8.9}\ \mu g/m^3)}_{\substack{\text{Contribution of}\\ \text{SULFATE}}} + \underbrace{.0144\ (\overset{\text{Average TSP - SULFATE - NITRATE}}{65.6}\ \mu g/m^3)}_{\substack{\text{Contribution of}\\ \text{TSP - SULFATE - NITRATE}}}$$

$$\text{or} \quad 2.18 = .12 + .02 + 1.10 + .94. \qquad (6\text{-}8)$$

Equation (6-8) indicates that, on the average for Oakland, 50% of extinction is from sulfates, 43% is from the non-sulfate, non-nitrate fraction of TSP, 6% is from air molecules, and 1% is unaccounted for.

Alternatively, we can compute an average extinction budget using the nonlinear RH regression model. For Oakland, Equation (6-6) reduces to

$$B = 0.49 + .0241\ \frac{\text{SULFATE}}{(1 - .01\ \text{RH})} + .0036\ \frac{\text{TSP - SULFATE - NITRATE}}{(1 - .01\ \text{RH})} \tag{6-9}$$

with a total correlation coefficient of 0.80. Substituting average values for B, SULFATE/(1 - .01 RH), and (TSP - SULFATE - NITRATE)/(1 - .01 RH), we obtain

$$2.18 = \underset{\substack{\uparrow \\ \text{Blue-sky} \\ \text{scatter}}}{.12} + \underset{\substack{\uparrow \\ \text{Remainder of constant term}}}{.37} + \underbrace{.0241\ (34.8)}_{\substack{\text{Contribution} \\ \text{of SULFATE}}} + \underbrace{.0036\ (239.3)}_{\text{Contribution of TSP - SULFATE - NITRATE}}$$

or

$$2.18 = .12 + .37 + .84 + .85 \tag{6-10}$$

Equation (6-10) indicates that, on the average for Oakland, 38% of extinction is from sulfates, 39% is from the non-sulfate, non-nitrate fraction of TSP, 6% is from air molecules, and 17% is unaccounted for.

6.1.4 Limitations of the Regression Studies

There are several limitations to the use of regression models for quantifying visibility/aerosol relationships. One limitation involves random errors in the data base produced by imprecision in the measurement techniques (for airport visibility or aerosol concentrations) and by the fact that the airport and Hi-Vol site are often located several miles apart. Random errors in the data tend to weaken the statistical relationships, leading to lower correlation coefficients and lower regression coefficients. This causes an underestimate of the extinction coefficients per unit mass for the aerosol species and, therefore, an underestimate of the contributions of the aerosol species to the total extinction budget. For this reason, some of the "unaccounted for" category probably represents additional contributions from sulfates, nitrates, and/or the remainder of TSP. The overall effect of random errors in the data base should not be excessive, however, because good correlations (typically 0.7 to 0.9) are usually obtained in the analysis.

Incompatibilities between the airport visibility data base and the aerosol data base can lead to at least two types of systematic bias. The aerosol concentrations measured at the downtown Hi-Vol locations may be systematically higher than the aerosol concentrations averaged over the visual range surrounding the airport. The bias caused by relatively high aerosol measurements would result in an underestimate of extinction coefficients per unit mass for the aerosol species. A reverse type of bias, e.g. an overestimate of extinction coefficients per unit mass, would result if daytime aerosol levels (corresponding to the time period of the visibility measurements) were higher than the 24-hour average aerosol levels measured by the Hi-Vol. Although these systematic errors could bias the extinction coefficients per unit mass, they should not bias the extinction budgets which are based on a multiplication of extinction coefficients per unit mass times the measured mass of the aerosol.

Another limitation is that the regression analysis may overstate the importance of the aerosol variables if these variables are correlated with other visibility-related pollutants omitted from the analysis. In particular, nitrates may act, in part, as surrogates for other related photochemical pollutants, such as secondary organic aerosols and nitrogen dioxide. For this reason, the nitrate contributions to the extinction budget might best be viewed as representing nitrate aerosols plus related photochemical pollutants.

Potential errors in Hi-Vol measurements of sulfate and nitrate are another important caveat. Artifact sulfate (formed by SO_2 conversion on the measurement filter) may cause a slight underestimation of the extinction coefficient per unit mass for sulfates. The greatest measurement concern, however, involves nitrates (Spicer and Schumacher 1979). Nitrate data may represent gaseous compounds (NO_2 and especially nitric acid) as well as nitrate aerosols. Also, high sulfate concentrations may negatively interfere with nitrate measurements (Harker et al. 1977). Because of potentially severe measurement errors, the visibility/nitrate relationships are especially uncertain.

A final difficulty in the regression analysis is the problem of colinearity, i.e. the intercorrelations that exist among the "independent" variables (sulfates, nitrates, remainder of TSP, and relative humidity). Although these intercorrelations (see Table 6.2) are not extremely high, they usually are significant (typically on the order of 0.2 to 0.7). Multiple regression is designed to estimate the individual effect of each variable, discounting for the simultaneous effects of other variables, but the colinearity problem can still lead to distortions in the results. It is likely that certain pollutant variables at certain sites are eliminated by statistical significance tests in the stepwise multiple regressions because these variables are colinear with another pollutant which bears a stronger relation to extinction. In such cases, the regression coefficient (extinction coefficient per unit mass) for the pollutant retained in the regression is likely to be artificially raised because it also is representing the effect of the colinear pollutants that did not pass the statistical significance tests.

TABLE 6.2 INTERCORRELATIONS AMONG THE INDEPENDENT VARIABLES IN THE VISIBILITY/AEROSOL REGRESSION STUDIES.

DATA: Excluding Days with Precipitation or Fog

	CORRELATION COEFFICIENTS					
LOCATION	S vs N	S vs T	S vs RH	N vs T	N vs RH	T vs RH
Burbank	.26	.17*	.13*	.43	-.03*	-.21
Long Beach	-.10*	.07*	.19	.36	-.17	-.49
Ontario	.40	.58	-.11*	.51	-.22*	-.27*
San Bernardino	.70	.67	.23*	.69	.19*	-.10*
Oakland	.38	.51	.08*	.44	-.13*	-.34
San Jose	.20	.08*	-.22	.58	.02*	.10*
Paso Robles	.41	.35	-.06*	.71	.02*	-.13*
San Diego	.26	.19	.34	.18	-.04*	-.48
Bakersfield	.88	.45	.32	.52	.26	-.18*
Fresno	.36	.12*	-.03*	.25	.18*	-.18*
Red Bluff	.51	.47	-.08*	.57	.03*	-.31
Sacramento	.35	.28	-.11*	.42	-.04*	-.32
Average Over Sites	.38	.33	.06	.47	.01	-.24

*Not statistically significant at 95% confidence level.

The above remarks have discussed limitations of the regression models in a rather general way. A more specific discussion of how these limitations may have affected the results reported herein is contained in the final section of this chapter.

6.2 DATA OVERVIEW

As indicated in Section 2.1.3 (Table 2.1, page 28), the visibility/aerosol regression analysis was attempted at 13 locations. At 12 of these locations, the regression model worked fairly well, at least in the sense that good levels of correlation were achieved. At one location, Barstow, we were unable to obtain reasonable regression or correlation coefficients. The problem with Barstow was that the visibility data had very little variance. The maximum visibility reported at Barstow is 35 miles, and 83% of the daily average visibilities ranged only from 30 to 35 miles, with 98% ranging only from 17 to 35 miles. Because the analysis failed at Barstow, only the results for the other twelve sites will be presented in this chapter.

At each location, the regression models were applied to two data sets; (1) eliminating days with precipitation or severe fog (defined as at least one daytime fog observation and average daytime relative humidity exceeding 96%) and (2) eliminating days with precipitation or any fog (defined as at least one daytime fog observation). The correlation coefficients for the first data set, typically about 0.85 to 0.90 for the nonlinear RH model [Equation (6-6)], were higher than those for the second data set, typically about 0.75 to 0.80 for the nonlinear RH model. The regression coefficients, however, were more consistent and physically reasonable for the second data set*. Only the results for the second data set will be described in this

*The days with fog included in the first data set generally represent days with very high extinction coefficients which contribute greatly to the total variance in the extinction data. These outliers evidently can be explained fairly well by the nonlinear RH regression models, leading to high correlation coefficients. A few outliers, however, can severly distort the regression coefficients, explaining why the regression coefficients tend to be less reasonable and consistent for the first data set.

chapter; Appendix D contains tabulations (similar to Tables 6.2 through 6.8) of corresponding results for the first data set.

Table 6.3 lists the number of data points and the average value for the regression variables at each study location. The sampling agencies, time periods, and measurement methods for the aerosol data were summarized previously in Table 2.1 (page 28).

Table 6.4 indicates the correlation coefficients between extinction and the four independent variables: S, N, T, and RH. It is evident that all four variables tend to correlate positively with extinction. The correlations are statistically significant at 11 of the 12 sites for sulfates (S), 10 of the sites for nitrates (N), 9 of the sites for relative humidity (RH), and 8 of the sites for the remainder of TSP (T). At most locations, extinction correlates best with sulfates.

6.3 MULTIPLE REGRESSIONS AND EXTINCTION BUDGETS

The results of stepwise multiple regressions are summarized in Tables 6.5 and 6.6 for the linear model [Equation (6-5)] and the nonlinear RH model [Equation (6-6)], respectively. For both regression models, the typical correlation coefficients are on the order of 0.75 to 0.80. Tables 6.5 and 6.6 list only those regression coefficients that are greater than zero at a 95% confidence level. At the 95% confidence level, the linear regression model retains relative humidity at 11 sites, nitrates at 9 sites, sulfates at 8 sites, and remainder of TSP at 6 sites. The nonlinear RH regression model retains NITRATE/(1 - .01 RH) at 9 sites, SULFATE/(1 - .01 RH) at 8 sites, and T/(1 - .01 RH) at 7 sites.

As explained in Section 6.1.3, the regression equations can be used to derive extinction budgets which indicate the fraction of haze, on the average, that is attributable to each pollutant species. Tables 6.7 and 6.8 present extinction budgets based on the linear regression model and nonlinear RH regression model, respectively. The tables list the fractions of total extinction due to blue-sky (Rayleigh) scatter, sulfates, nitrates, and the remainder of TSP. The last category is "unaccounted for"; this category is negative at some sites, indicating that blue-sky scatter plus the terms in

TABLE 6.3 SUMMARY STATISTICS FOR LOCATIONS INCLUDED IN VISIBILITY/AEROSOL REGRESSION STUDIES.

DATA: Excluding Days with Precipitation or Fog

LOCATION	NUMBER OF DATA POINTS	AVERAGE VALUES FOR KEY PARAMETERS: $B = 24.3/V$ $(10^4\ m)^{-1}$	$S = 1.3SO_4^{=}$ $(\mu g/m^3)$	$N = 1.3NO_3^-$ $(\mu g/m^3)$	$T = TSP - S - N$ $(\mu g/m^3)$	RH (%)
SOUTH COAST AIR BASIN						
Burbank	107	2.67	12.4	11.6	108.4	47.9
Long Beach	139	2.81	14.0	8.8	83.6	54.1
Ontario	51	4.16	11.8	12.8	101.9	44.0
San Bernardino	56	3.15	13.8	14.7	94.5	42.8
SAN FRANCISCO BAY AREA AIR BASIN						
Oakland	179	2.18	8.9	4.9	65.6	70.7
San Jose	119	1.75	3.3	7.5	56.4	68.7
OTHER COASTAL LOCATIONS						
Paso Robles	70	1.16	7.1	5.9	67.3	46.5
San Diego	161	2.48	9.8	6.4	56.5	61.0
SAN JOAQUIN VALLEY AIR BASIN						
Bakersfield	102	2.50	13.4	20.2	134.4	44.2
Fresno	86	1.97	6.7	10.3	117.1	46.3
SACRAMENTO VALLEY AIR BASIN						
Red Bluff	69	0.68	3.9	5.3	64.8	40.6
Sacramento	131	1.75	6.4	5.5	63.2	50.4

TABLE 6.4 CORRELATION BETWEEN EXTINCTION AND THE INDEPENDENT VARIABLES.

DATA: Excluding Days with Precipitation or Fog

LOCATION	CORRELATION COEFFICIENTS B vs S	B vs N	B vs T	B vs RH
SOUTH COAST AIR BASIN				
Burbank	.63	.06*	.07*	.54
Long Beach	.72	.08*	.15*	.34
Ontario	.52	.40	.41	.26*
San Bernardino	.75	.68	.64	.39
SAN FRANCISCO BAY AREA AIR BASIN				
Oakland	.75	.36	.55	.24
San Jose	.07*	.53	.35	.40
OTHER COASTAL LOCATIONS				
Paso Robles	.49	.70	.60	.31
San Diego	.75	.28	.13*	.39
SAN JOAQUIN VALLEY AIR BASIN				
Bakersfield	.83	.90	.38	.38
Fresno	.34	.78	.21*	.17*
SACRAMENTO VALLEY AIR BASIN				
Red Bluff	.29	.51	.52	.18*
Sacramento	.51	.40	.36	.28
Average Over Sites	.55	.47	.36	.32

*Not statistically significant at 95% confidence level.

TABLE 6.5 SUMMARY OF LINEAR EXTINCTION/AEROSOL REGRESSIONS.

DATA: Excluding Days with Precipitation or Fog

REGRESSION EQUATION: $B = a' + b_1S + b_2N + b_3T + b_4(RH - \overline{RH})$

LOCATION	TOTAL CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS a'	b_1	b_2	b_3	b_4
SOUTH COAST AIR BASIN						
Burbank	.78	.58	.17	NS	NS	.080
Long Beach	.79	-.75	.16	.04	.011	.047
Ontario	.67	.28	.16	.15	NS	.067
San Bernardino	.83	-.34	.12	NS	.019	.059
SAN FRANCISCO BAY AREA AIR BASIN						
Oakland	.83	.14	.12	NS	.014	.040
San Jose	.66	1.34	NS	.06	NS	.027
OTHER COASTAL LOCATIONS						
Paso Robles	.82	-.37	.08	.08	.008	.022
San Diego	.77	.33	.19	.04	NS	.019
SAN JOAQUIN VALLEY AIR BASIN						
Bakersfield	.91	.61	NS	.09	NS	.023
Fresno	.78	.49	NS	.14	NS	NS
SACRAMENTO VALLEY AIR BASIN						
Red Bluff	.65	-.06	NS	.03	.009	.013
Sacramento	.71	-.43	.16	.05	.014	.044

NS = Not significantly greater than zero at the 95% confidence level.

TABLE 6.6 SUMMARY OF NONLINEAR RH EXTINCTION/AEROSOL REGRESSIONS.

DATA: Excluding Days with Precipitation or Fog

REGRESSION EQUATION: $B = a + b_1 \frac{S}{1 - \frac{RH}{100}} + b_2 \frac{N}{1 - \frac{RH}{100}} + b_3 \frac{T}{1 - \frac{RH}{100}}$

LOCATION	TOTAL CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS a'	b_1	b_2	b_3
SOUTH COAST AIR BASIN					
Burbank	.80	-.33	.079	NS	.004
Long Beach	.79	.04	.051	NS	.006
Ontario	.66	.38	.095	.063	NS
San Bernardino	.85	-.64	.037	.029	.011
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	.80	.49	.024	NS	.004
San Jose	.55	1.39	NS	.013	NS
OTHER COASTAL LOCATIONS					
Paso Robles	.82	-.15	.031	.042	.003
San Diego	.79	.42	.060	.020	NS
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	.92	.78	NS	.041	NS
Fresno	.76	1.09	NS	.040	NS
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	.68	-.07	NS	.022	.005
Sacramento	.82	-.49	.076	.016	.007

NS = Not significantly greater than zero at the 95% confidence level.

TABLE 6.7 EXTINCTION BUDGETS BASED ON THE LINEAR REGRESSION MODEL.

DATA: Eliminating Days with Precipitation or Fog

LOCATION	CONTRIBUTIONS TO TOTAL EXTINCTION				
	Blue-sky Scatter	Sulfates	Nitrates	Remainder of TSP	Unaccounted for
SOUTH COAST AIR BASIN					
Burbank	4%	79%	0%	0%	17%
Long Beach	4%	80%	13%	33%	-30%
Ontario	3%	46%	46%	0%	5%
San Bernardino	4%	53%	0%	57%	-14%
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	6%	50%	0%	43%	1%
San Jose	7%	0%	25%	0%	68%
OTHER COASTAL LOCATIONS					
Paso Robles	10%	48%	40%	44%	-42%
San Diego	5%	75%	11%	0%	9%
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	5%	0%	75%	0%	20%
Fresno	6%	0%	75%	0%	19%
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	18%	0%	23%	85%	-26%
Sacramento	7%	58%	16%	50%	-31%
Average for All Sites	6%	41%	27%	26%	0%

Note: The zero contributions for certain aerosol species imply only that a statistically significant relationship was not observed in the multiple regressions and do not necessarily mean that the actual contributions are zero (see discussion on page 135).

TABLE 6.8 EXTINCTION BUDGETS BASED ON THE NONLINEAR RH REGRESSION MODEL.

DATA: Eliminating Days with Precipitation or Fog

LOCATION	CONTRIBUTIONS TO TOTAL EXTINCTION				
	Blue-sky Scatter	Sulfates	Nitrates	Remainder of TSP	Unaccounted for
SOUTH COAST AIR BASIN					
Burbank	4%	80%	0%	33%	-17%
Long Beach	4%	61%	0%	38%	- 3%
Ontario	3%	53%	38%	0%	6%
San Bernardino	4%	32%	27%	61%	-24%
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	6%	38%	0%	39%	17%
San Jose	7%	0%	21%	0%	72%
OTHER COASTAL LOCATIONS					
Paso Robles	10%	37%	42%	34%	-23%
San Diego	5%	69%	14%	0%	12%
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	5%	0%	69%	0%	26%
Fresno	6%	0%	45%	0%	49%
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	18%	0%	30%	80%	-28%
Sacramento	7%	61%	11%	55%	-34%
Average for All Sites	6%	36%	25%	28%	5%

Note: The zero contributions for certain aerosol species imply only that a statistically significant relationship was not observed in the multiple regressions and do not necessarily mean that the actual contributions are zero (see discussion on page 135).

the regression equations more than account for average extinction levels at those sites.

The estimated percentage contributions for certain aerosol species are zero at some sites. These estimates of zero contribution imply only that a statistically significant relationship was not observed in the multiple regression and do not necessarily mean that the actual contributions are zero. As noted in Section 6.1.4, statistical difficulties introduced by intercorrelations among the aerosol variables can lead to non-significant regression coefficients (and zero contributions) for certain aerosol species while, at the same time, inflating the regression coefficients (and estimated contributions) for other aerosol species. Methods of overcoming this problem will be discussed in the next section.

Tables 6.7 and 6.8 indicate that, averaged over the 12 sites, sulfates account for approximately 40% of total extinction, while nitrates and remainder of TSP each account for slightly more than 25% of extinction. Sulfates seem to be relatively more important at the southern sites (the four SCAB locations and San Diego); nitrates appear to be relatively more important in the San Joaquin Valley; and the remainder of TSP seems to be relatively more important in the Sacramento Valley.

Averaged over the 12 sites, blue-sky scatter contributes 6% to total extinction. The fixed contribution from natural blue-sky scatter is, of course, a greater percentage of total extinction at the sites with better visibility (i.e. smaller extinction). If we had been able to include mountain/desert sites with exceptional average visibility (50 to 80 miles), a simple calculation shows that blue-sky scatter would account for 25 to 40% of total extinction at such sites.

All of the above results are based on the data set excluding days with precipitation or <u>any</u> fog. As noted previously, Appendix D presents corresponding results for the data set excluding days with precipitation or the very few days with <u>severe</u> fog. The main difference in the results presented in Appendix D is that the sulfate contributions are emphasized even more (representing approximately 50 to 60% of total extinction averaged over the 12 sites). In other words, we find a greater contribution from sulfates if we include most of the days with fog observations. This reflects the tendency for high sulfate levels to form during conditions of high relative humidity (Cass 1977; Duckworth 1979).

6.4 DISCUSSION OF RESULTS

Table 6.9 summarizes the extinction coefficients per unit mass for sulfates, nitrates, and remainder of TSP obtained in this study and compares them to corresponding results obtained in other regression studies. Table 6.9a is for California locations, while Table 6.9b is for sites in the Northeast and Rocky Mountain Southwest. Most of the coefficients listed in Table 6.9 represent the parameters b_1, b_2, and b_3 in Equation (6-5), the linear regression model; those coefficients that are marked with an asterisk represent the terms $b_1/(1 - .01\ RH)$, $b_2/(1 - .01\ RH)$, and $b_3/(1 - .01\ RH)$ in Equation (6-6), the nonlinear RH regression model, with the insertion of average relative humidity for the sites.

Viewing all of the regression studies as a whole, there is general agreement that the extinction coefficients per unit mass for secondary aerosols (sulfates and nitrates) are nearly one order of magnitude greater than extinction coefficients per unit mass for the remainder of TSP. Qualitatively, this agrees with known principles of aerosol physics. Secondary aerosols tend to form in the particle size range of 0.1 to 1 micron, called the "accumulation" size range (NRC 1979; Whitby and Cantrell 1976; Willeke and Whitby 1975; Hidy et al. 1974). The remainder of TSP mass is usually dominated by the coarse particle mode residing in a size range above 2 microns (Whitby and Sverdrup 1978; Bradway and Record 1976; Willeke and Whitby 1975). As shown in Figure 6.1, light-scattering per unit mass of aerosol as a function of particle size exhibits a pronounced peak at a particle size of about 0.5 microns, and particles in the 0.1 to 1 micron size range scatter much more light per unit mass than particles above 2 microns in size.

Table 6.10 presents a quantitative comparison of extinction coefficients per unit mass obtained in empirical (regression) studies and theoretical studies. The empirical values tend to be somewhat higher than the theoretical values, especially for sulfates at California sites and the remainder

TABLE 6.9 SUMMARY OF EXTINCTION COEFFICIENTS PER UNIT MASS OBTAINED IN VARIOUS REGRESSION STUDIES.

Table 6.9a Locations in California.

LOCATION	EXTINCTION COEFFICIENTS PER UNIT MASS $(10^4\ m)^{-1}/(\mu g/m^3)$ Sulfates	Nitrates	Remainder of TSP
<u>Other Studies</u>			
SOUTH COAST AIR BASIN (White and Roberts 1977) Various Los Angeles Basin Sites†	.07* .06	.05* .04	.015* .020
(Cass 1979) Downtown Los Angeles	.17* .09	NS* .05	.008 NS*
(Grosjean et al. 1976) Eastern Los Angeles Basin	.21	.04	NS
(Leaderer and Stolwijk 1979) Los Angeles Int. Airport	.16	.03	NS
<u>The Present Study</u>			
SOUTH COAST AIR BASIN Burbank	.17* .15	NS* NS	NS * .008
Long Beach	.16* .11	.04* NS	.011* .013
Ontario	.16* .17	.15* .11	NS* NS
San Bernardino	.12* .06	NS* .05	.019* .019
SAN FRANCISCO BAY AREA AIR BASIN Oakland	.12* .08	NS* NS	.014* .014
San Jose	NS* NS	.06* .04	NS* NS
OTHER COASTAL LOCATIONS Paso Robles	.08* .06	.08* .08	.008* .006
San Diego	.19* .15	.04* .05	NS* NS
SAN JOAQUIN VALLEY AIR BASIN Bakersfield	NS* NS	.09* .07	NS* NS
Fresno	NS* NS	.14* .07	NS* NS
SACRAMENTO VALLEY AIR BASIN Red Bluff	NS* NS	.03* .04	.009* .008
Sacramento	.16* .15	.05* .03	.014* .014

*Values marked by an asterisk are based on the nonlinear RH regression model with insertion of average RH. Values not so marked are based on the linear RH model.

†Based on nephelometry data rather than airport visibility data.

TABLE 6.9 SUMMARY OF EXTINCTION COEFFICIENTS PER UNIT MASS OBTAINED IN VARIOUS REGRESSION STUDIES (Continued).

Table 6.9b Locations in the Northeast and Rocky Mountain Southwest.

LOCATION	EXTINCTION COEFFICIENTS PER UNIT MASS $(10^4\ m)^{-1}/(\mu g/m^3)$ Sulfates	Nitrates	Remainder of TSP
NORTHEAST			
(Trijonis and Yuan, 1978b)			
Chicago	.04* .03	NS* NS	NS* NS
Newark	NS* .06	NS* NS	.026* .014
Cleveland	.08 .07	NS* NS	NS* NS
Lexington	.06* .06	NS* NS	NS* .019
Charlotte.	.11* .11	NS* NS	NS* NS
Columbus	.12* .13	.09* .06	NS* NS
(Leaderer and Stolwijk 1979)			
New York†	.07	.05	NS
New York	.10	NS	NS
New Haven	.16	NS	NS
St. Louis	.08	NS	NS
ROCKY MOUNTAIN SOUTHWEST			
(Trijonis 1979)			
Phoenix			
County Data	.04	.05	NS
NASN Data	.03	.03	NS
Salt Lake City	.04* .04	.13* .10	.004* .004

*Values marked by an asterisk are based on the nonlinear RH regression model with insertion of average RH. Values not so marked are based on the linear RH model.

†Based on nephelometry data rather than airport visibility data.

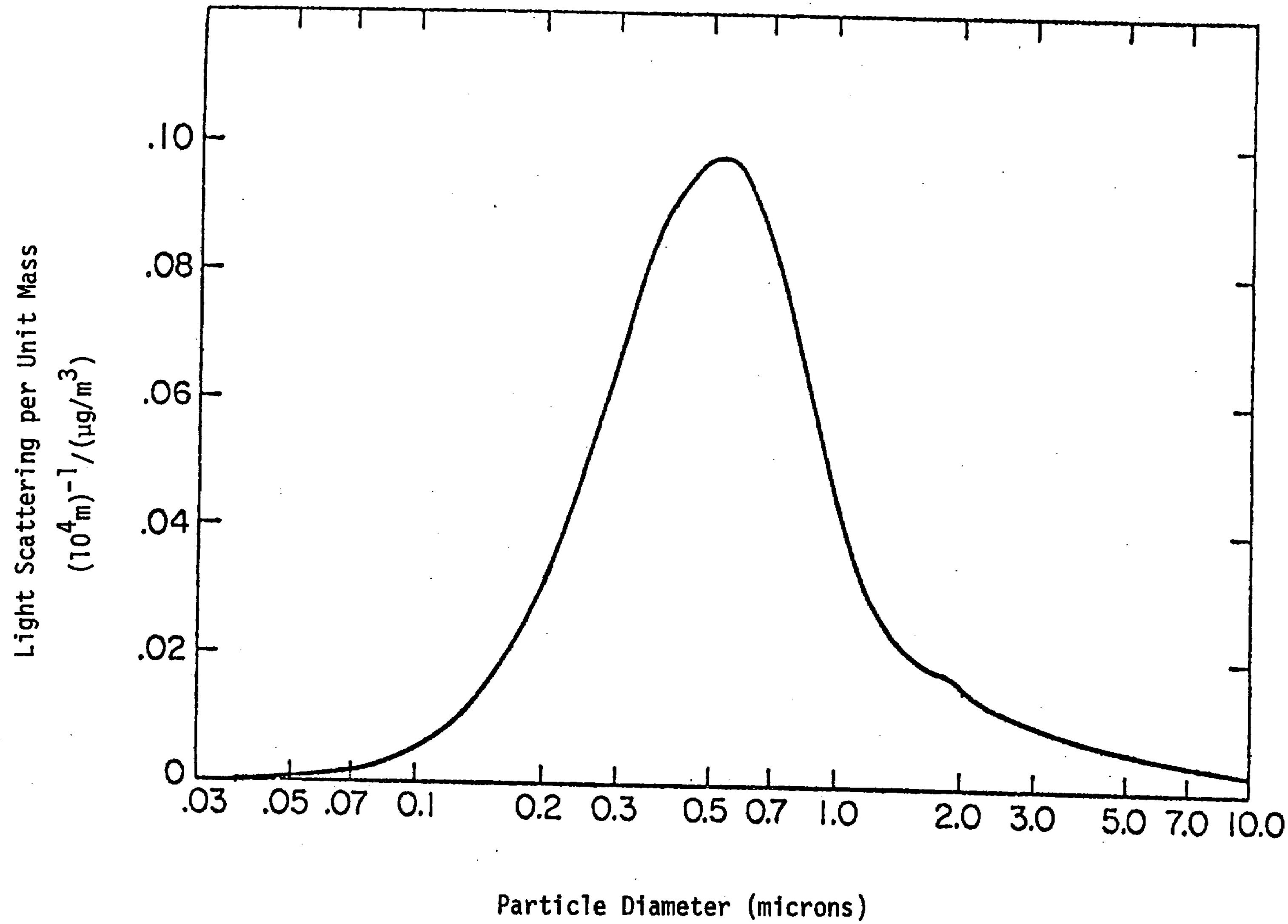


Figure 6.1 Light scattering by aerosols as a function of particle diameter. Computed for unit density spherical particles of refractive index 1.5 (White and Roberts 1977).

TABLE 6.10 COMPARISON OF EMPIRICAL AND THEORETICAL EXTINCTION COEFFICIENTS PER UNIT MASS.

EXTINCTION COEFFICIENTS PER UNIT MASS, IN UNITS OF $(10^4\ m)^{-1}/(\mu g/m^3)$

TYPICAL ± RANGE

AEROSOL SPECIES	EMPIRICAL STUDIES† California Sites	Non-California Sites	THEORETICAL STUDIES††
SULFATES	.13 ± .05	.08 ± .04	.06 ± .03
NITRATES	.06 ± .03	.07 ± .03	Not Calculated (Possibly about the same as sulfates)
REMAINDER OF TSP	.013 ± .004	.013 ± .010	.006 ± .03

†The "typical" values for the empirical studies are the averages of all statistically significant coefficients in Tables 6.9a and 6.9b; the "range" is the standard deviation of these data.

††The "typical" values for the theoretical studies are based on Mie Theory calculations reported by Latimer et al. (1978), White and Roberts (1977), and Ursenbach et al. (1978). The "range" represents variance among individual locations with respect to particle size distributions and relative humidity.

of TSP at all sites. Referring back to our discussion of limitations of the regression models (Section 6.1.4), there appears to be two basic reasons for this discrepancy:

(1) Daytime aerosol concentrations (corresponding to the time of the visibility measurements) tend to be higher than the 24 hour aerosol concentrations that are used in our analysis. Data for Los Angeles (Hidy et al. 1974) suggest that daytime averages exceed 24-hour averages by approximately a factor of 1.25 for sulfates, 1.3 for nitrates, and 1.15 for the remainder of TSP. Data for the San Joaquin Valley (Basket 1980) indicate daytime/24-hour factors of 1.07 for sulfates, 1.02 for nitrates, and 1.10 for the remainder of TSP.* The estimates of extinction coefficients per unit mass in the regression model will be biased upward according to the factor by which daytime concentrations exceed 24-hour average concentrations.

(2) Statistical problems also lead to overestimates of the extinction coefficients per unit mass. As noted previously, when one variable is omitted from the multiple regression equation due to lack of statistical significance, the coefficients for the remaining variables (which tend to be correlated with the omitted variable) are inflated because they partially represent the effect of the omitted variable. Furthermore, including only the statistically significant coefficients in compiling Table 6.10 biases the average empirical values upward because those locations where the coefficient are too small to be statistically significant are excluded from the average.

Overestimating the extinction coefficients per unit mass due to differences between daytime and 24-hour aerosol concentrations is not a problem in the extinction budgets; there is a cancellation of effects because the (inflated) coefficients are multiplied by the (deflated) concentrations in deriving the extinction budgets. The statistical problems, however, do adversely affect the extinction budgets. As noted in Section 6.3, the statistically insignificant variables are unreasonably assigned zero contributions to total extinction, while the contributions of the statistically significant variables are inflated due to colinearity problems.

Further work needs to be done in order to resolve the statistical problems. One analysis that might be tried is to retain the coefficients

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*Note that the daytime averages can exceed the 24-hour averages by at most a factor of two; even if the 12-hour nighttime concentrations are zero, the 24-hour average equals one-half the daytime average.

of all variables in the regression equation, regardless of statistical significance. This analysis, however, would not totally solve the colinearity problems; also, one would have to decide how to deal with the occassional negative coefficients that appear in such regressions. A more promising approach is to consider both the empirical and theoretical results and propose a general equation that is applicable to all California sites. For example, considering all the results and problems, we propose the following general equation for deriving extinction budgets in California*.

$$B = \frac{.04\ S}{(1 - \frac{RH}{100})} + \frac{.03\ N}{(1 - \frac{RH}{100})} + \frac{.003\ T}{(1 - \frac{RH}{100})} + \underbrace{.12}_{\substack{\text{Blue-sky}\\ \text{scatter}}} + \underbrace{\Delta}_{\substack{\text{Unaccounted for = average}\\ \text{value of B minus other terms}}} \qquad (6\text{-}11)$$

Substituting in average values for B, S/(1 - .01 RH), ...etc. at each site, we arrive at the extinction budgets listed in Table 6.11. It can be seen that Equation (6-11) does account for the total amount of extinction fairly well at most sites (the notable exceptions being Ontario and Red Bluff).

The approach represented by Equation (6-11) can be refined and improved in at least two major areas. First, regression models might be run for even more sites in California to provide information that would allow Equation (6-11) to be made region specific. In other words, it might be better to have four or five equations specific to individual parts of California. Second, more terms might be added to the equation by using chemical element tracer methods to further separate out individual fractions of the aerosol. For example, lead might be used to trace primary automotive particles, silicon or aluminum might be used to trace soil dust, etc.

*For comparison with the coefficients in Tables 6.9 and 6.10, it should be noted that, at typical average relative humidity ($\sim$ 50%), the coefficients are .08 $(10^4\ m)^{-1}/(\mu g/m^3)$ for sulfates, 0.6 for nitrates, and .006 for the remainder of TSP.

TABLE 6.11 EXTINCTION BUDGETS BASED ON A SINGLE, GENERAL EXTINCTION EQUATION.

LOCATION	CONTRIBUTIONS TO TOTAL EXTINCTION				
	Blue-sky Scatter	Sulfates	Nitrates	Remainder of TSP	Unaccounted for
SOUTH COAST AIR BASIN					
Burbank	4%	40%	27%	25%	4%
Long Beach	4%	49%	22%	20%	5%
Ontario	3%	22%	18%	14%	43%
San Bernardino	4%	34%	27%	16%	19%
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	6%	64%	25%	33%	-28%
San Jose	7%	26%	49%	37%	-19%
OTHER COASTAL LOCATIONS					
Paso Robles	10%	48%	30%	34%	-22%
San Diego	5%	46%	21%	18%	10%
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	5%	44%	51%	31%	-31%
Fresno	6%	28%	33%	34%	- 1%
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	18%	41%	42%	49%	-50%
Sacramento	7%	32%	21%	23%	17%
Average for All Sites	7%	39%	30%	28%	- 4%

7.0 HISTORICAL VISIBILITY TRENDS

Many Californians hold strong qualitative opinions concerning historical changes in California visibility. For example, the opinion is often voiced that visibility in many parts of California is significantly worse now than it was 25 or 30 years ago. In the more recent past -- over the last 10 to 15 years -- some people have remarked about improving visibility in certain areas (e.g. the central Los Angeles region). The weather station visibility data provide a unique opportunity to check such perceptions in a quantitative manner.

This chapter documents long-term visibility changes for the period 1949 to 1976 at 19 locations in-and-near California. The chapter begins with a discussion of data quality problems in visibility trend analysis (Section 7.1). Section 7.2 describes overall visibility changes based on annual data with no sorting for meteorology. In Section 7.3, the seasonal aspects of historical visibility changes are examined. Section 7.4 presents visibility trends that have been stratified by meteorological class. In Section 7.5 our conclusions regarding visibility trends in various areas are summarized and potential causes of historical visibility changes are discussed; Section 7.5 also presents data on ambient aerosol trends and compares our results to other recently published studies on visibility trends in certain parts of California. Finally, Section 7.6 investigates the possibliity that changes in haze levels have affected climate in California.

7.1 CHANGES IN OBSERVATION LOCATIONS AND REPORTING PRACTICES

As noted in Section 2.1.2, the only major problem with the quality of the visibility data in this report involves the analysis of historical visibility trends. In examining historical trends, we are often dealing with actual visibility changes of 20% or less. Fluctuations of this magnitude can sometimes also be produced artificially by changes in observation locations and/or reporting practices.

Two statistical tests are used to investigate whether changes in observation locations significantly altered reported visibility levels. These two tests, a t-test on the net jump in quarterly medians and a multivariate regression test on the jump in seasonally adjusted quarterly medians, are described in Appendix E. Each test estimates the net jump in visibility produced by the relocation and the statistical significance of that jump.

Table 7.1 lists relocations that occurred at the trend study sites from 1949 to 1976 and summarizes the results of the statistical tests. For each statistical test, Table 7.1 lists the estimated net jump in median visibility (both in miles and percent), the t-statistic for the jump, and the significance level for the jump (the confidence level that the t-statistic is different from zero). Based on the estimated net percentage jump in visibility, the significance level of the jump, and the agreement between the two statistical tests, the last column of Table 7.1 presents our overall conclusion as to whether or not the relocation produced a significant change in reported visibilities. The conclusions are listed as either "significant", "possibly significant", or "apparently not significant".

Our analysis of consistency in reporting practices is only qualitative in nature; it is based on a visual scan of yearly frequency distributions in order to identify the routinely reported visibilities each year. The results of this analysis are described in the center column of Table 7.2. Table 7.2 also summarizes the site relocations and indicates our decisions regarding which stations and time periods to include in the historical trend analysis. Of the 25 stations that we originally considered as potential sites for the historical trend study only 19 had data of adequate quality for the study.

7.2 YEARLY VISIBILITY TRENDS

This section documents visibility trends based on yearly data with no sorting for meteorology. Our analysis of historical trends is based on visibility percentiles, usually the 50th percentile or median visibility.* This method differs from the traditional method (Holzworth 1960, 1962;

*Techniques for determining median visibility or other visibility percentiles from the cumulative frequency distributions are discussed in Section 2.2.

TABLE 7.1 ANALYSIS OF THE STATISTICAL SIGNIFICANCE OF OBSERVATION SITE RELOCATIONS ON REPORTED AIRPORT VISIBILITIES.

STATION	MONTH MOVED	DISTANCE MOVED (miles)	t-TEST ON JUMP IN QUARTERLY MEDIANS: Net Jump in Visibility (miles)	(percent)	t Value for Jump	Significance level of t Value	REGRESSION TEST ON JUMP IN SEASONALLY ADJUSTED QUARTERLY MEDIANS: Net Jump in Visibility (miles)	(percent)	t Value for Jump	Significance level of t Value	CONCLUSION
SOUTH COAST AIR BASIN											
Downtown Los Angeles	2/40	~0.5	+0.4	+ 5	0.5		+0.3	+ 3	0.3		Apparently Not Significant
Downtown Los Angeles	6/64	~0.5	-0.8	-14	0.9		-1.2	-20	2.2	>95%	Significant
Long Beach	10/57	0.8	+1.0	+14	1.1		+0.4	+ 5	0.8		Apparently Not Significant
SAN FRANCISCO BAY AREA AIR BASIN											
Oakland	6/65	2nd to 1st floor	-1.2	-10	2.7	>95%	-2.2	-18	6.5	>99%	Significant
San Francisco Int.	6/55	0.7	-0.5	- 4	0.5		-1.7	-15	2.7	>99%	Possibly Significant
OTHER COASTAL LOCATIONS											
San Diego	8/69	0.04	-2.1	-16	2.2		-0.7	- 5	0.6		Possibly Significant
Santa Maria	2/72	0.2	+1.5	+ 8	1.2		-0.8	- 5	0.8		Apparently Not Significant
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN											
Bakersfield	3/58	0.3	-2.1	-15	2.9	>95%	-0.7	- 5	0.8		Possibly Significant
Fresno	9/61	0.9	-0.3	- 2	0.1		+1.2	+ 9	0.9		Apparently Not Significant
Sacramento	5/56	0.02	+0.6	+ 3	1.3		-0.8	+ 4	0.7		Apparently Not Significant
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON											
Medford	5/53	0.1	+1.5	+ 7	1.2		-0.8	+ 4	0.7		Apparently Not Significant
Medford	1/69	0.04	+2.1	+11	1.8		-0.8	+ 4	0.7		Apparently Not Significant
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA											
Yuma	4/75	0.03	+1.2	+ 2	1.1		Insufficient data available for this analysis				Apparently Not Significant

TABLE 7.2 SUMMARY OF DATA QUALITY RESTRICTIONS ON THE ANALYSIS OF HISTORICAL VISIBILITY TRENDS.

AIR BASIN/LOCATION	TIME PERIOD WITH COMPUTERIZED DATA	CHANGES IN REPORTING PRACTICES	CHANGES IN OBSERVATION SITES	DECISION ON DATA TO BE INCLUDED IN STUDIES
SOUTH COAST AIR BASIN				
Downtown Los Angeles*	1933-1976*	No significant changes noted.*	1940: Apparently not significant. 1964: Significant.	Consider data before-and-after 1964 separately.
Long Beach	1949-1976	A minor change in the late 1950's.	1957: Apparently not significant.	Use all data.
San Bernardino	1949-1970	Several changes prior to 1959.	Several moves prior to 1959.	Use data for 1959-1970.
Sandberg	1949-1976	Numerous reporting changes leading to erratic data.		Eliminate.
San Nicolas	1949-1976	Several minor changes during 1949-1976.		Use all data but attach caveat about reporting changes.
SAN FRANCISCO BAY AREA AIR BASIN				
Fairfield	1949-1970	Reporting changes in 1950, 1953, and 1956.		Use data for 1957-1970.
Oakland	1949-1976		1965: Significant.	Consider data before-and-after 1965 separately.
San Francisco	1949-1976		1955: Possibly significant.	Use all data but attach caveat about site relocation.
OTHER COASTAL LOCATIONS				
Arcata	1950-1976	Several minor changes during 1949-1976.		Use all data but attach caveat about reporting changes.
Monterey	1949-1970	Numerous reporting changes leading to erratic data.		Eliminate.
Santa Maria	1955-1976	Significant reporting change in 1974.	1972: Apparently not significant.	Use data for 1955-1973.
San Diego	1949-1976	Several reporting changes during 1970's.	1969: Possibly significant.	Use data for 1949-1968.

*Note that the data for Downtown Los Angeles have been obtained from Ralph Keith (1970; 1979a) rather than from the National Climatic Center computerized data base.

TABLE 7.2 SUMMARY OF DATA QUALITY RESTRICTIONS ON THE ANALYSIS OF HISTORICAL VISIBILITY TRENDS (Continued).

AIR BASIN/LOCATION	TIME PERIOD WITH COMPUTERIZED DATA	CHANGES IN REPORTING PRACTICES	CHANGES IN OBSERVATION SITES	DECISION ON DATA TO BE INCLUDED IN STUDIES
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN				
Bakersfield	1949-1976	Several reporting changes during early 1950's.	1958: Possibly significant.	Use all data but attach caveat about 1950's data.
Fresno	1950-1976		1961: Apparently insignificant.	Use all data.
Sacramento	1949-1976		1956: Apparently not significant.	Use all data.
Stockton	1964-1976			Use all data.
NORTHEASTERN CALIFORNIA, SOUTHERN OREGON, AND WESTERN NEVADA				
Bishop	1949-1976	Major reporting change in 1952.		Use data for 1953-1976.
Blue Canyon	1949-1976	Numerous reporting changes leading to erratic data.		Eliminate.
Burns	1951-1976			Use all data.
Medford	1949-1976		1953: Apparently not significant. 1969: Apparently not significant.	Use all data.
Red Bluff	1949-1976			Use all data.
Tonopah	1951-1976	Distant marker not used until 1973.		Eliminate.
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA				
Barstow	1949-1976	Several major reporting changes.		Eliminate.
China Lake	1949-1976	Several major reporting changes.		Eliminate.
Yuma	1949-1976	Several major reporting changes during the 1950's.	1975: Apparently not significant.	Use data for 1960-1976.

Neiburger 1955; Keith 1964, 1970, 1979b; Green and Battan 1967; Miller et al. 1972; Hartman 1972; Duckworth and Kinney 1978) which examines shifts in the fraction of days (or hours) that visibility is in certain ranges. The units of our visibility trend index are [miles], while the units of the traditional index are [percent of days] or [percent of hours].

7.2.1 Plots of Annual Trends

Figures 7.1 through 7.6 illustrate yearly trends in median visibility for six geographical areas: the South Coast Air Basin; San Francisco Bay Area Air Basin; Other Coastal Locations; San Joaquin Valley/Southern Sacramento Valley Air Basins; Northeastern California and Southern Oregon; and·Southeast Desert Air Basin and Western Arizona. The trends are based on data for all four daylight hours, typically 1460 annual measurements (365 days x 4 hours per day). To smooth the trends somewhat, the data are plotted as three-year moving averages (from 1950 to 1975 for stations with data from 1949 to 1976).

A close examination of Figures 7.1 through 7.6 indicates that the visibility trends tend to split naturally into two sub-periods, divided at approximately 1966. From 1950 to 1966, nearly all locations exhibit deteriorating visibility, with especially large visibility decreases occurring in-and-near the Central Valley (e.g. at Bakersfield, Fresno, Sacramento, Red Bluff, Santa Maria, and Fairfield). From 1966 to 1975, nearly all the locations display improving visibility. The only notable exceptions to these rules are Long Beach, San Francisco, Oakland, and Bishop which demonstrate improving visibility through both periods, and Stockton, Sacramento, and Yuma, which show no improvement from 1966 to 1975.

7.2.2 Net Percent Changes in Visibility

Table 7.3 summarizes the net percent changes in three-year-average visibility from 1949-1951 to 1965-1967. The percent changes are listed for best-case visibility (10th to 30th percentiles), median visibility (50th percentile), and worst-case visibility (90th percentile). For several sites, the trends had to be extrapolated from data covering some, but not all, of the period in question. As noted previously, most locations exhibit

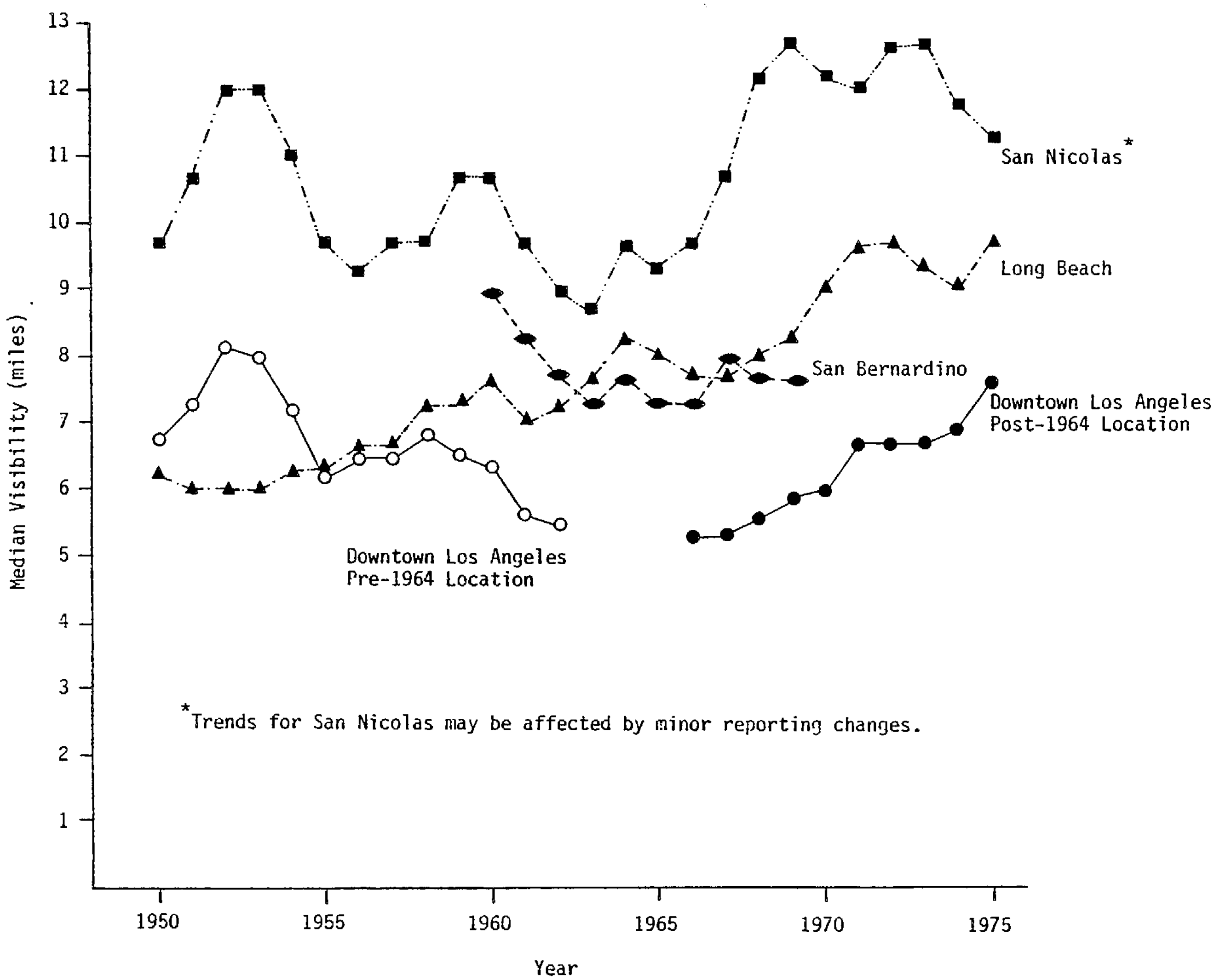

Figure 7.1 Historical visibility trends for the South Coast Air Basin, three-year moving averages of yearly median visibilities from 1949 to 1976.

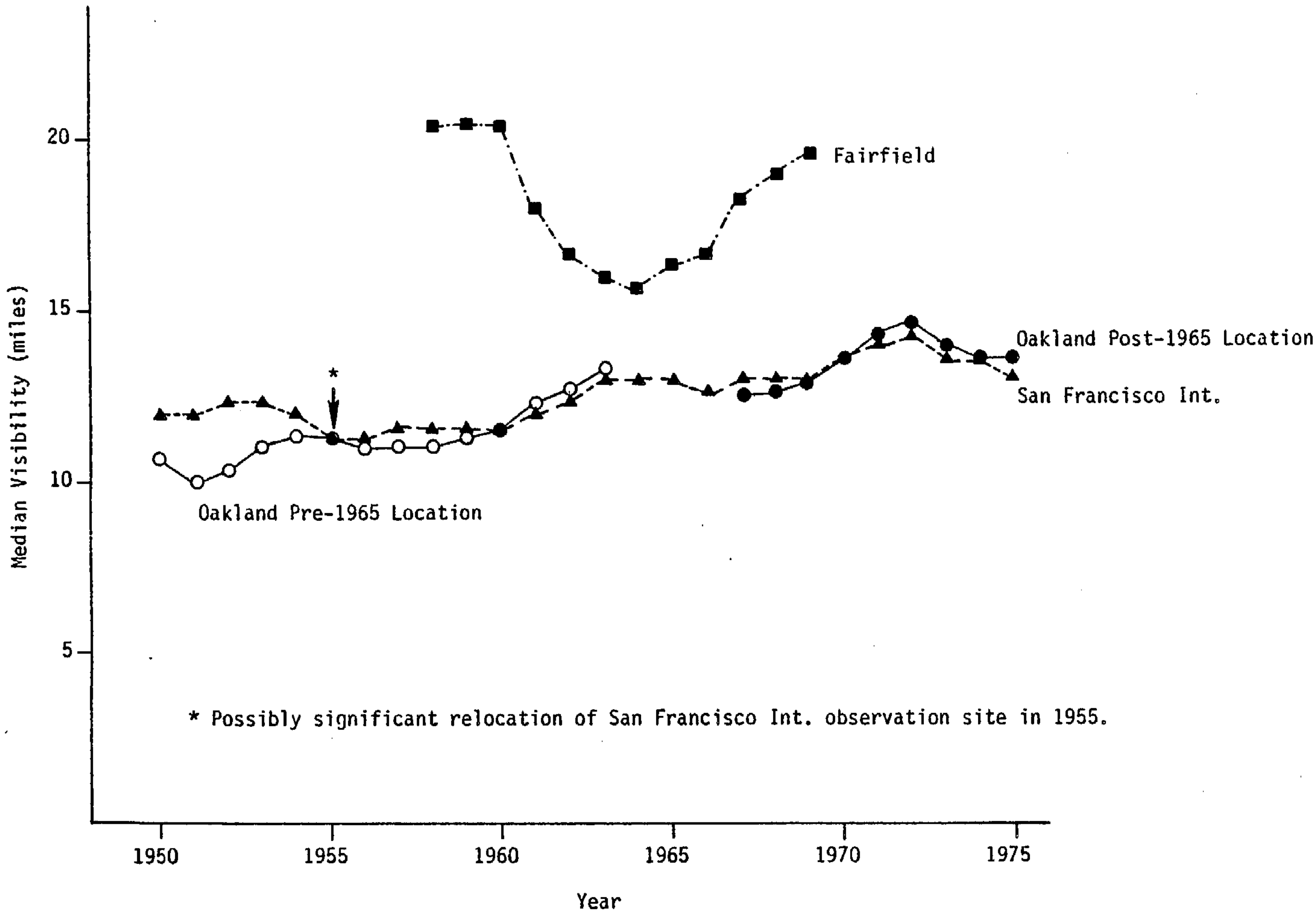

Figure 7.2 Historical visibility trends for the San Francisco Bay Area Air Basin, three-year moving averages of yearly median visibilities from 1949 to 1976.

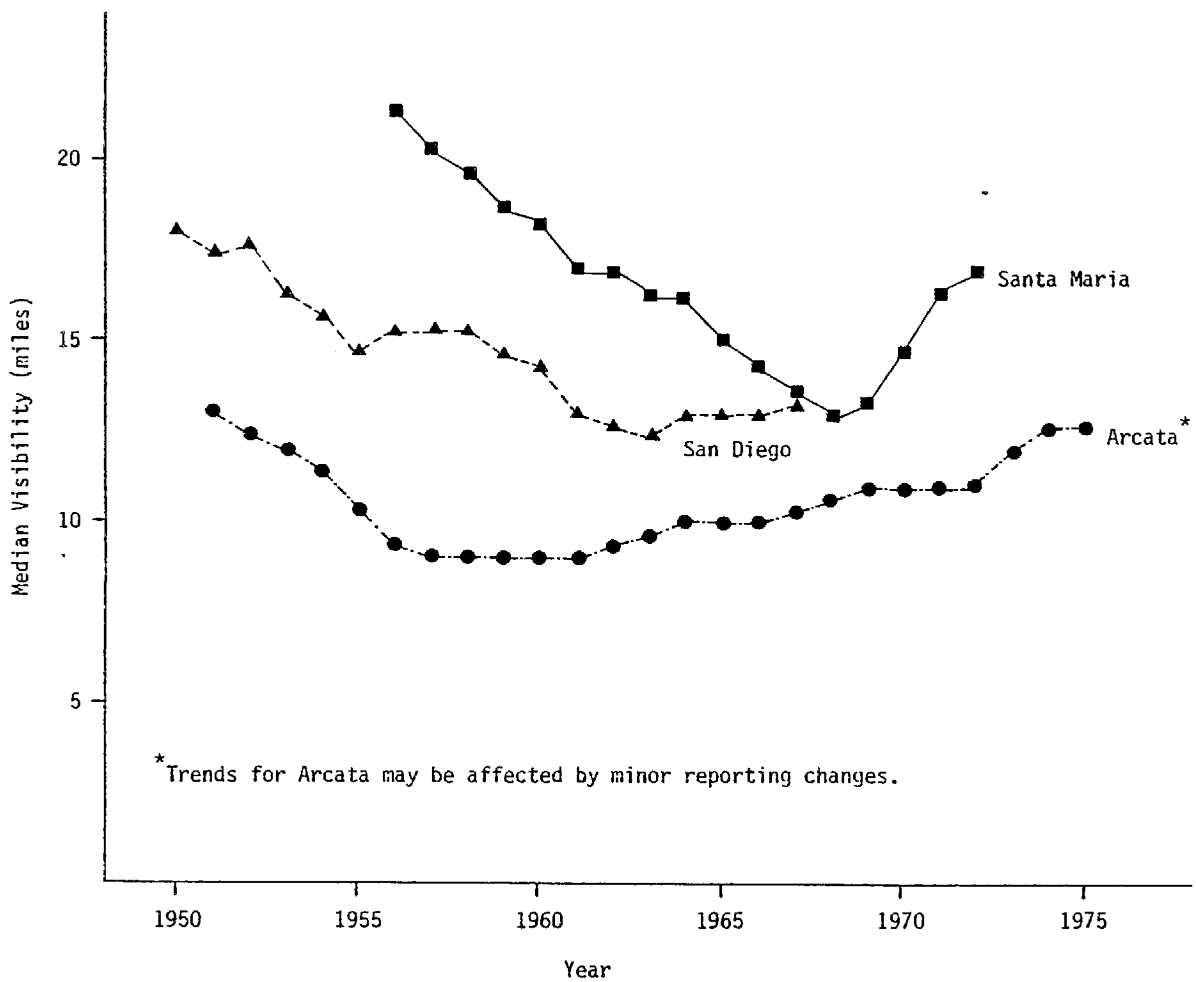

Figure 7.3 Historical visibility trends for other coastal locations, three-year moving averages of yearly median visibilities from 1949 to 1976.

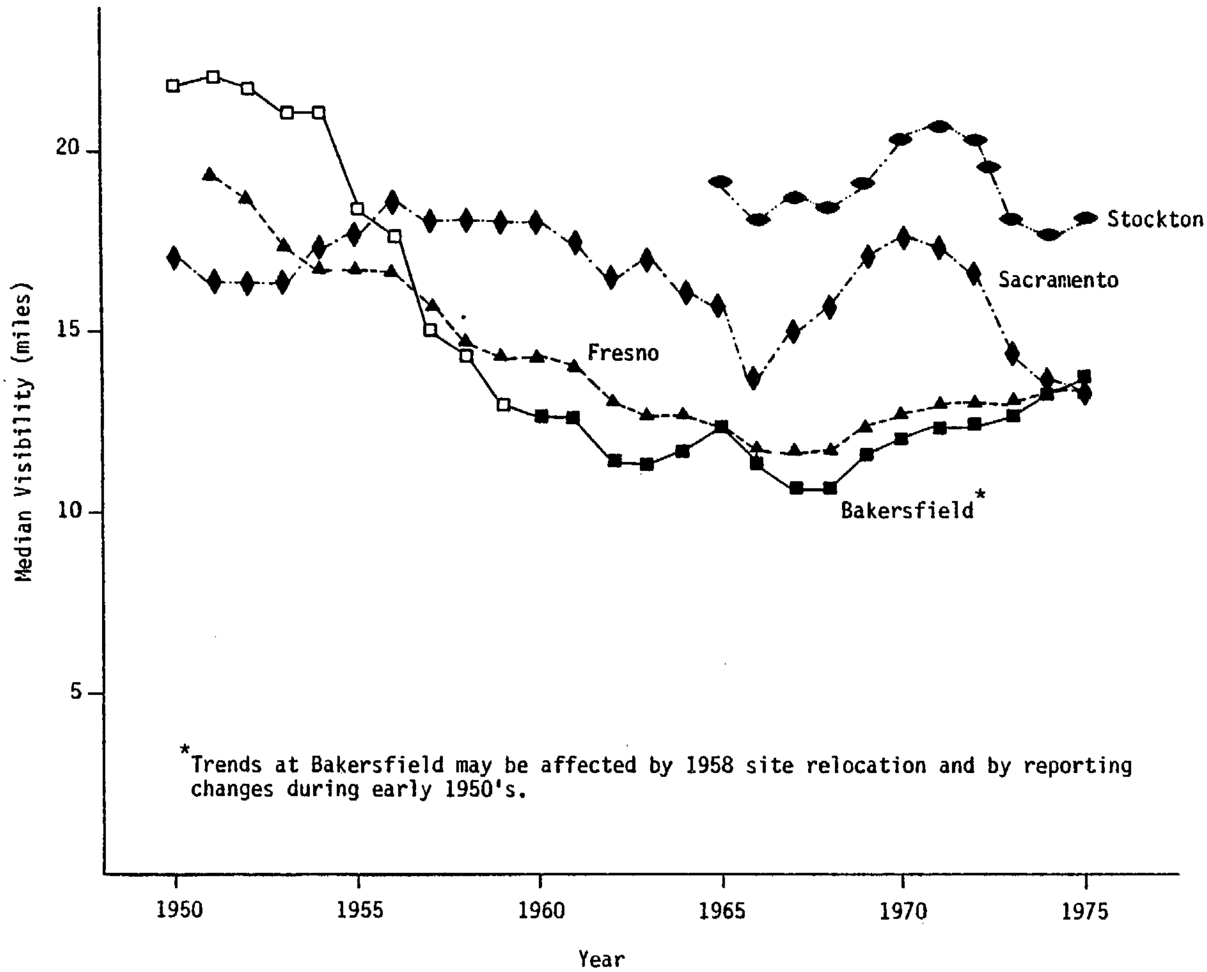

Figure 7.4 Historical visibility trends for the San Joaquin Valley and southern Sacramento Valley, three-year moving averages of yearly median visibilities from 1949 to 1976.

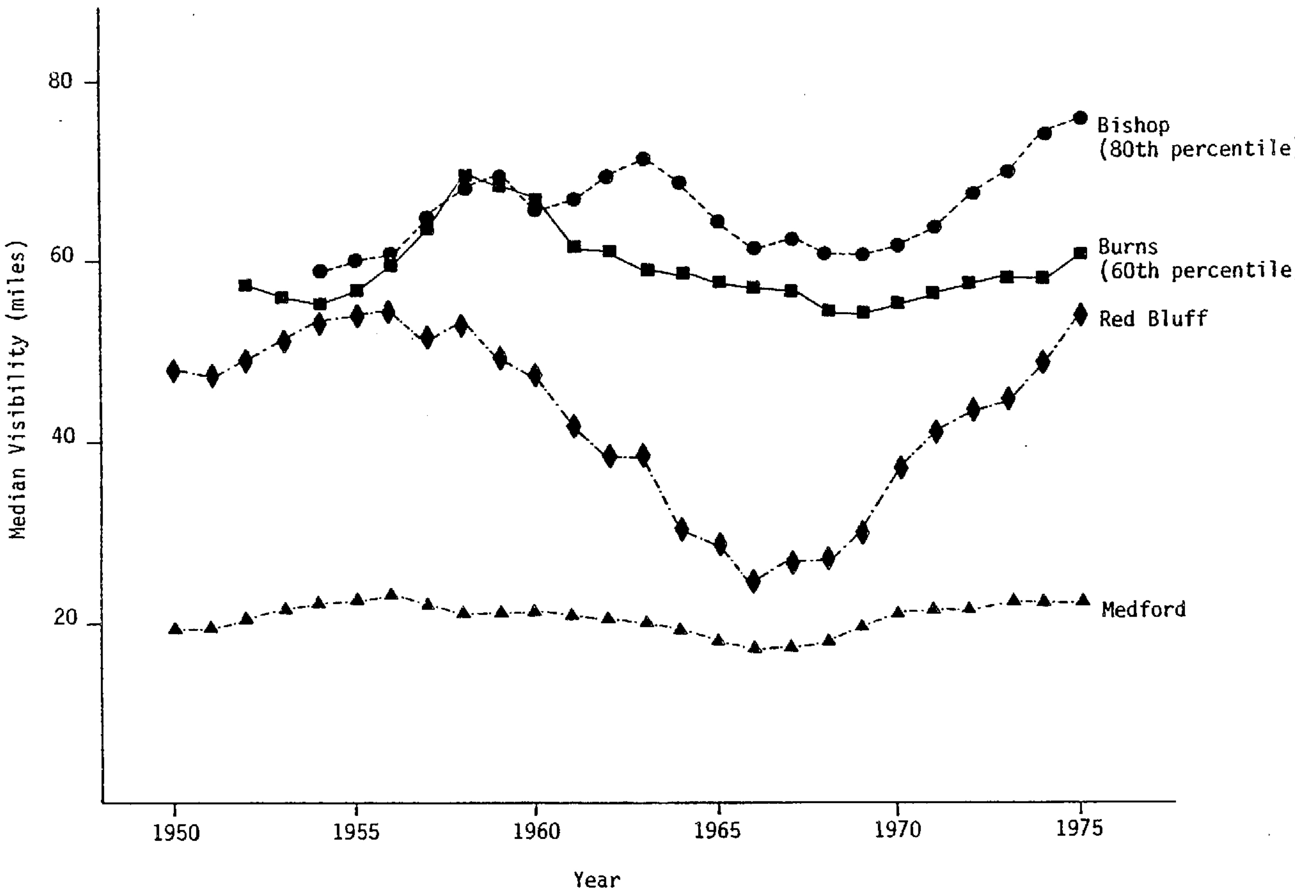

Figure 7.5 Historical visibility trends for northeastern California and southern Oregon, three-year moving averages of yearly median visibilities from 1949 to 1976.

Figure 7.6 Historical visibility trends for the Southeast Desert Air Basin and western Arizona, three-year moving averages of yearly median visibilities from 1949 to 1976.

TABLE 7.3 NET PERCENT CHANGES IN VISIBILITY, 1949-1951 TO 1965-1967.

AIR BASIN/LOCATION	BEST-CASE VISIBILITY (10th - 30th Percentile)	MEDIAN VISIBILITY (50th Percentile)	WORST-CASE VISIBILITY (90th Percentile)
SOUTH COAST AIR BASIN			
Downtown Los Angeles†	-25%[a]	-25%	-21%
Long Beach	+28%[b]	+22%	0%
San Bernardino†	-44%[b]	-38%	-29%
San Nicolas*	-18%[a]	+ 2%	+23%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield†	-36%[c]	-30%	-46%
Oakland†	+17%[a]	+22%	+22%
San Francisco Int.*	+43%[b]	+ 6%	+21%
OTHER COASTAL LOCATIONS			
Arcata†*	-17%[c]	-24%	0%
San Diego	-25%[b]	-28%	- 6%
Santa Maria†	-31%[c]	-44%	-25%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN			
Bakersfield*	-27%[b]	-48%	-35%
Fresno†	-43%[a]	-41%	-54%
Sacramento	- 2%[a]	-19%	-23%
Stockton	I	I	I
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop†	NC	+ 7%[d]	+ 3%
Burns†	NC	- 1%[e]	- 3%
Medford	- 1%[c]	-12%	-23%
Red Bluff	-17%[b]	-49%	-44%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA			
Yuma†	+ 5%[b]	-19%	-10%

†Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]10th percentile.

[b]20th percentile.

[c]30th percentile.

[d]80th percentile rather than median.

[e]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

deteriorating visibilities from 1949-1951 to 1965-1967. In particular, Downtown Los Angeles, San Bernardino, Fairfield, Arcata, San Diego, Santa Maria, Bakersfield, Fresno, Sacramento, and Red Bluff displayed decreases in visibility on the order of 20 to 40%. The largest decreases occurred at locations in or near the Central Valley. Three sites, Long Beach, Oakland, and San Francisco, underwent moderate ($\sim$20%) improvements in visibility.

Table 7.4 lists net percent changes in visibility from 1965-1967 to 1974-1976. All sites except Sacramento, Stockton, and Yuma (which display little change) show visibility improvements on the order of 10 to 60% during this period.

Table 7.5 lists net changes in visibility from 1949-1951 to 1974-1976, obtained simply by multiplying the factors reflected in Tables 7.3 and 7.4.* Over the entire two and one-half decades, it is evident that the major areas experiencing improved visibility were the central/coastal parts of both the South Coast Air Basin (Downtown Los Angeles, Long Beach, and San Nicolas) and the San Francisco Bay Area Air Basin (Oakland and San Francisco Int.). The densely populated, central/coastal portions of these metropolitan regions underwent improvements in visibility on the order of 10 to 40%. Slight improvements in visibility also seem evident in the northeastern California/southern Oregon region. The major areas that experienced deterioration in visibility -- on the order of 10 to 30% -- were the San Joaquin and southern Sacramento Valleys (Bakersfield, Fresno, and Sacramento), the South Central Coast Air Basin (Santa Maria), the inland South Coast Air Basin (San Bernardino), and the Southeast Desert Air Basin (Yuma).

7.2.3 Downtown Los Angeles Visibility Trends, 1933 to 1976

The historical trend data for Downtown Los Angeles used in this report have been taken from the work of Ralph Keith (1970, 1979a) rather than from National Climatic Center data tapes. The record for Downtown Los Angeles is unique in the sense that Keith has compiled data covering over four decades,

*For example, if a location underwent a 30% visibility decrease from 1949-1951 to 1965-1967 and a 20% visibility increase from 1965-1967 to 1974-1976, the net change over the entire period would be $(1 - .30)(1 + .20) = .7 \times 1.2 = .84$ = a 16% decrease.

TABLE 7.4 NET PERCENT CHANGES IN VISIBILITY, 1965-1967 TO 1974-1976.

AIR BASIN/LOCATION	BEST-CASE VISIBILITY (10th - 30th Percentile)	MEDIAN VISIBILITY (50th Percentile)	WORST-CASE VISIBILITY (90th Percentile)
SOUTH COAST AIR BASIN			
Downtown Los Angeles	+38%[a]	+43%	+58%
Long Beach	+17%[b]	+26%	+35%
San Bernardino[†]	+81%[b]	+16%	0%
San Nicolas*	+56%[a]	+14%	+16%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield[†]	+70%[c]	+54%	+53%
Oakland[†]	+ 9%[a]	+ 9%	+22%
San Francisco Int.	+ 1%[b]	+ 2%	+14%
OTHER COASTAL LOCATIONS			
Arcata*	+22%[c]	+27%	0%
San Diego	I	I	I
Santa Maria[†]	+33%[c]	+29%	+18%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN			
Bakersfield	+22%[b]	+21%	0%
Fresno	+12%[a]	+14%	+12%
Sacramento	-21%[a]	- 3%	+12%
Stockton	+ 2%[b]	0%	+10%
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop	NC	+23%[d]	+ 8%
Burns	NC	+ 6%[e]	+11%
Medford	+13%[c]	+29%	- 9%
Red Bluff	+27%[b]	+122%	+59%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA			
Yuma	- 7%[b]	+ 3%	0%

[†]Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]10th percentile.

[b]20th percentile.

[c]30th percentile.

[d]80th percentile rather than median.

[e]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

TABLE 7.5 NET PERCENT CHANGES IN VISIBILITY, 1949-1951 TO 1974-1976.

AIR BASIN/LOCATION	BEST-CASE VISIBILITY (10th - 30th Percentile)	MEDIAN VISIBILITY (50th Percentile)	WORST-CASE VISIBILITY (90th Percentile)
SOUTH COAST AIR BASIN			
Downtown Los Angeles†	+ 4%[a]	+ 7%	+25%
Long Beach	+50%[b]	+54%	+35%
San Bernardino†	+ 1%[b]	-28%	-29%
San Nicolas*	+28%[a]	+16%	+43%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield†	+ 9%[c]	+ 8%	-17%
Oakland†	+28%[a]	+33%	+49%
San Francisco Int.*	+44%[b]	+ 8%	+38%
OTHER COASTAL LOCATIONS			
Arcata†*	+ 1%[c]	- 3%	0%
San Diego	I	I	I
Santa Maria†	- 8%[c]	-28%	-11%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN			
Bakersfield*	-11%[b]	-37%	-35%
Fresno†	-36%[a]	-33%	-48%
Sacramento	-23%[a]	-21%	-14%
Stockton	I	I	I
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop†	NC	+32%[d]	+11%
Burns†	NC	+ 5%[e]	+ 8%
Medford	+12%[c]	+14%	-30%
Red Bluff	+ 5%[b]	+13%	-11%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA			
Yuma†	- 2%[b]	-17%	-10%

†Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]10th percentile.

[b]20th percentile.

[c]30th percentile.

[d]80th percentile rather than median.

[e]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

1933 to 1976. We have used his compilation of the frequency of (non-weekend) days with noon visibility in various ranges to compute trends in best 10th percentile, median, and worst 90th percentile visibility for that entire period. The results, plotted as three-year moving averages, are presented in Figure 7.7.

As noted by Keith, visibility at Downtown Los Angeles has gone through cycles: a sharp deterioration during the industrial expansion of the early 1940's; significant improvement with the onset of air pollution controls in the late 1940's and early 1950's; gradual deterioration from the early 1950's to the early 1960's as growth (especially in automotive traffic) evidently outstripped stationary source controls; and improvement from the middle 1960's to the middle 1970's as automotive controls came into effect and stationary source controls were further tightened. It also has been proposed, however, that meteorological cycles -- rather than source growth and air pollution controls -- may be the major cause of these observed visibility cycles (Porch and Ellsaesser 1977).

Comparing the middle 1930's to the middle 1970's*, it is obvious that the principal change occurred on the days of best visibility; the best 10th percentile decreased from about 40 miles to less than 25 miles. In contrast, the median and 90th percentile visibilities have not exhibited much net change from the 1930's to the 1970's and may have even increased somewhat. The decrease in 10th percentile visibility relative to the median or 90th percentile may be related to the spreading nature of growth in the Los Angeles basin, to meteorological trends, and/or to undocumented changes in visibility reporting procedures.

In order to help explain the 1933-1976 visibility trends in Los Angeles, it would be useful to quantify historical emission changes over that period. There are some indications that emissions of certain visibility related pollutants (e.g. SO_x, hydrocarbons, and particulates) may have been as great in the 1930's as in the 1970's (Carlin and Kocher 1971). Quantifying

*Actually, to account for the effect of the site relocation in 1964, the post-1964 values should be raised slightly (possibly as much as 15 to 20%, see Table 7.1).

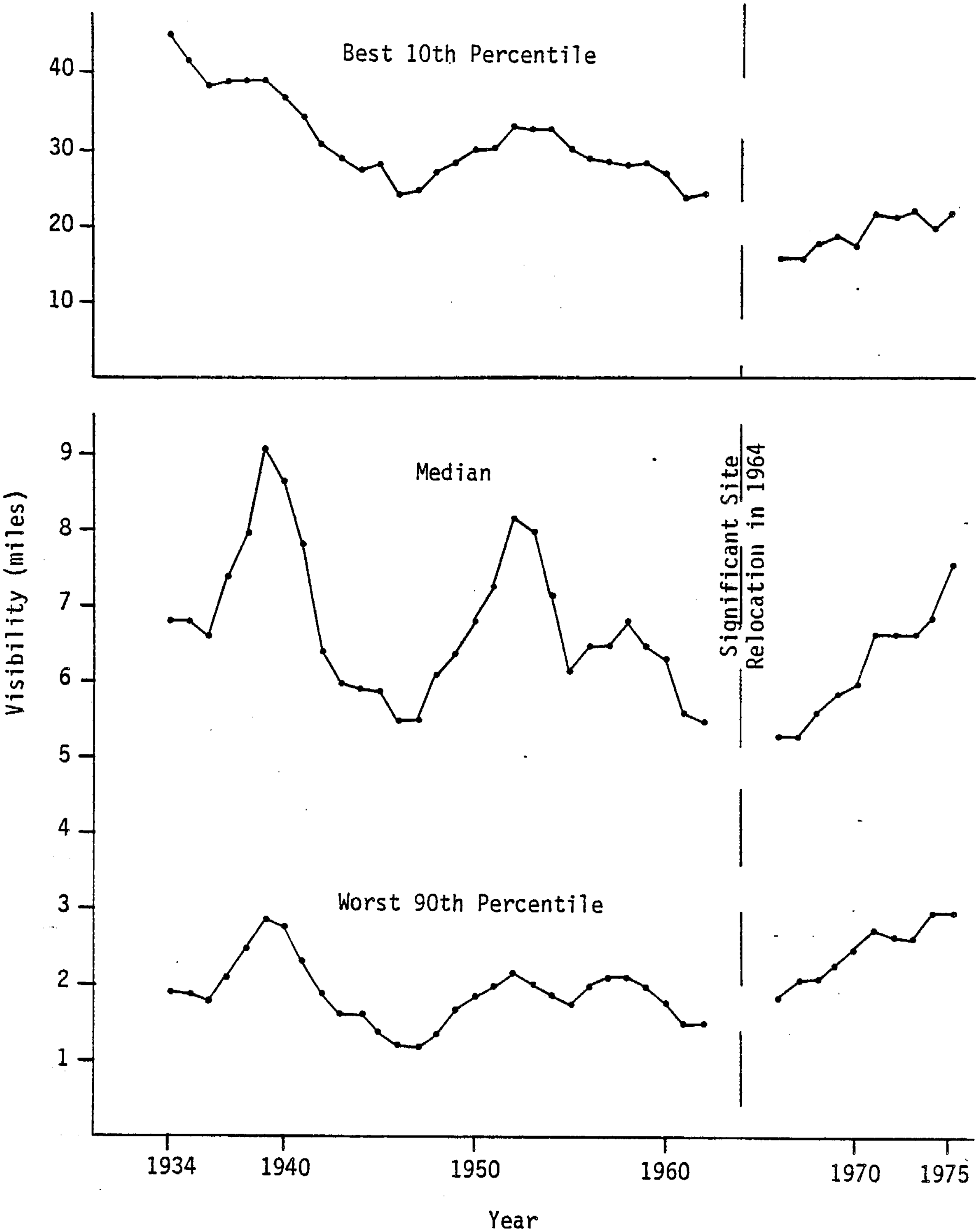

Figure 7.7 Historical visibility trends at Downtown Los Angeles, three-year moving averages of yearly median visibilities from 1933 to 1976.

historical emission trends back to the 1930's may well be possible (Marians and Trijonis 1979), and this task should be given consideration as a potential area for future research.

7.3 SEASONAL VISIBILITY TRENDS

Tables 7.6 through 7.8 indicate the net percent changes in median visibility by quarter of the year for the periods 1949-1951 to 1965-1967, 1965-1967 to 1974-1976, and 1949-1951 to 1974-1976, respectively.* Close examination of Table 7.6 indicates that, at most locations, the deterioration of visibility from 1949-1951 to 1965-1967 was most pronounced in the winter and fall seasons, especially the winter. This pattern is particularly intense at the three sites in the San Joaquin Valley and southern Sacramento Valley. The major exceptions to the above rule are the desert/mountain sites (Bishop, Burns, and Yuma) where the greatest visibility decrease occurred in the spring.

Table 7.7 reveals no strong, consistent seasonal patterns in the visibility increases that occurred from 1965-1967 to 1974-1976. The one minor pattern that emerges is the tendency for the visibility increases to be somewhat greater in the winter and spring quarters.

Over the entire period 1949-1951 to 1974-1976 (Table 7.8), the one outstanding seasonal feature in the trends is the deterioration of winter/fall visibility relative to spring/summer in the San Joaquin Valley and Sacramento Valley. This phenomenon is illustrated in Figure 7.8 for Bakersfield and Fresno and in Figure 7.9 for Sacramento and Red Bluff. It can be seen that, during the early 1950's, winter and fall median visibilities were about the same as summer median visibility and slightly worse than spring median visibility. By the middle 1970's, winter and fall median visibilities were about two-thirds of summertime values and about one-half of springtime values.

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*The reader should note that the average of the percent changes in the medians over the four quarters (Tables 7.6 through 7.8) does not necessarily equal the net percent change in the yearly medians (Tables 7.3 through 7.5). Also, Downtown Los Angeles is excluded from Tables 7.6 through 7.8 because quarterly data were not readily available for that site.

TABLE 7.6 NET PERCENT CHANGES IN SEASONAL VISIBILITIES, 1949-1951 TO 1965-1967.

AIR BASIN/LOCATION	CHANGE IN SEASONAL MEDIAN VISIBILITIES			
	1st Quarter Winter	2nd Quarter Spring	3rd Quarter Summer	4th Quarter Fall
SOUTH COAST AIR BASIN				
Long Beach	+16%	+32%	+25%	+11%
San Bernardino†	-43%	-34%	-18%	-47%
San Nicolas*	-13%	+ 2%	+29%	+33%
SAN FRANCISCO BAY AREA AIR BASIN				
Fairfield†	-43%	-41%	-24%	-18%
Oakland†	+ 2%	+30%	+33%	+24%
San Francisco Int.*	-18%	+ 7%	+ 3%	+10%
OTHER COASTAL LOCATIONS				
Arcata†*	-36%	-26%	-11%	-13%
San Diego	-33%	-28%	-18%	-31%
Santa Maria†	-39%	-52%	-47%	-37%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN				
Bakersfield	-61%	-33%	-37%	-63%
Fresno†	-66%	-41%	-28%	-63%
Sacramento	-47%	- 1%	- 4%	-30%
Stockton	I	I	I	I
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON				
Bishop†a	+15%	-16%	-12%	+23%
Burns†b	+ 2%	-21%	+22%	- 5%
Medford	-32%	+ 4%	- 9%	-26%
Red Bluff	-56%	-51%	-40%	-53%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA				
Yuma†	- 2%	-35%	-26%	-17%

†Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

TABLE 7.7 NET PERCENT CHANGES IN SEASONAL VISIBILITIES, 1965-1967 TO 1974-1976.

AIR BASIN/LOCATION	CHANGE IN SEASONAL MEDIAN VISIBILITIES			
	1st Quarter Winter	2nd Quarter Spring	3rd Quarter Summer	4th Quarter Fall
SOUTH COAST AIR BASIN				
Long Beach	+40%	+11%	+22%	+66%
San Bernardino†	+29%	+68%	0%	+44%
San Nicolas*	+10%	+14%	0%	- 3%
SAN FRANCISCO BAY AREA AIR BASIN				
Fairfield†	+119%	+54%	+58%	+17%
Oakland†	+31%	+20%	+ 1%	- 8%
San Francisco Int.	+34%	+22%	+ 3%	-12%
OTHER COASTAL LOCATIONS				
Arcata*	+33%	+49%	+24%	+13%
San Diego	I	I	I	I
Santa Maria†	+19%	+28%	+34%	+64%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN				
Bakersfield	+41%	+38%	+19%	+ 8%
Fresno	+21%	+20%	+16%	+ 9%
Sacramento	+13%	-28%	-14%	+ 6%
Stockton	+35%	+ 3%	- 4%	+21%
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON				
Bishop[a]	0%	+61%	+16%	+17%
Burns[b]	- 2%	+11%	+12%	+12%
Medford	+30%	+19%	+29%	+ 9%
Red Bluff	+55%	+132%	+127%	+88%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA				
Yuma	- 2%	+11%	+ 7%	+ 1%

†Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

TABLE 7.8 NET PERCENT CHANGES IN SEASONAL VISIBILITIES, 1949-1951 TO 1974-1976.

AIR BASIN/LOCATION	CHANGE IN SEASONAL MEDIAN VISIBILITIES			
	1st Quarter Winter	2nd Quarter Spring	3rd Quarter Summer	4th Qaurter Fall
SOUTH COAST AIR BASIN				
Long Beach	+62%	+47%	+52%	+84%
San Bernardino†	-26%	+11%	-18%	-24%
San Nicolas*	- 4%	+16%	+29%	+29%
SAN FRANCISCO BAY AREA AIR BASIN				
Fairfield†	+25%	- 9%	+20%	- 4%
Oakland†	+34%	+56%	+34%	+14%
San Francisco Int.*	+10%	+31%	+ 6%	- 3%
OTHER COASTAL LOCATIONS				
Arcata†*	-15%	+10%	+10%	- 2%
San Diego	I	I	I	I
Santa Maria†	-27%	-39%	-29%	+ 3%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN				
Bakersfield*	-45%	- 8%	-25%	-60%
Fresno†	-59%	-29%	-16%	-60%
Sacramento	-40%	+ 2%	-17%	-26%
Stockton	I	I	I	I
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON				
Bishop†a	+15%	+35%	+30%	+31%
Burns†b	0%	-12%	+37%	+ 6%
Medford	-12%	+24%	+17%	-19%
Red Bluff	-32%	+14%	+36%	-12%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA				
Yuma†	- 4%	-28%	-21%	-16%

†Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

I = Insufficient period of data to estimate net percent change in visibility.

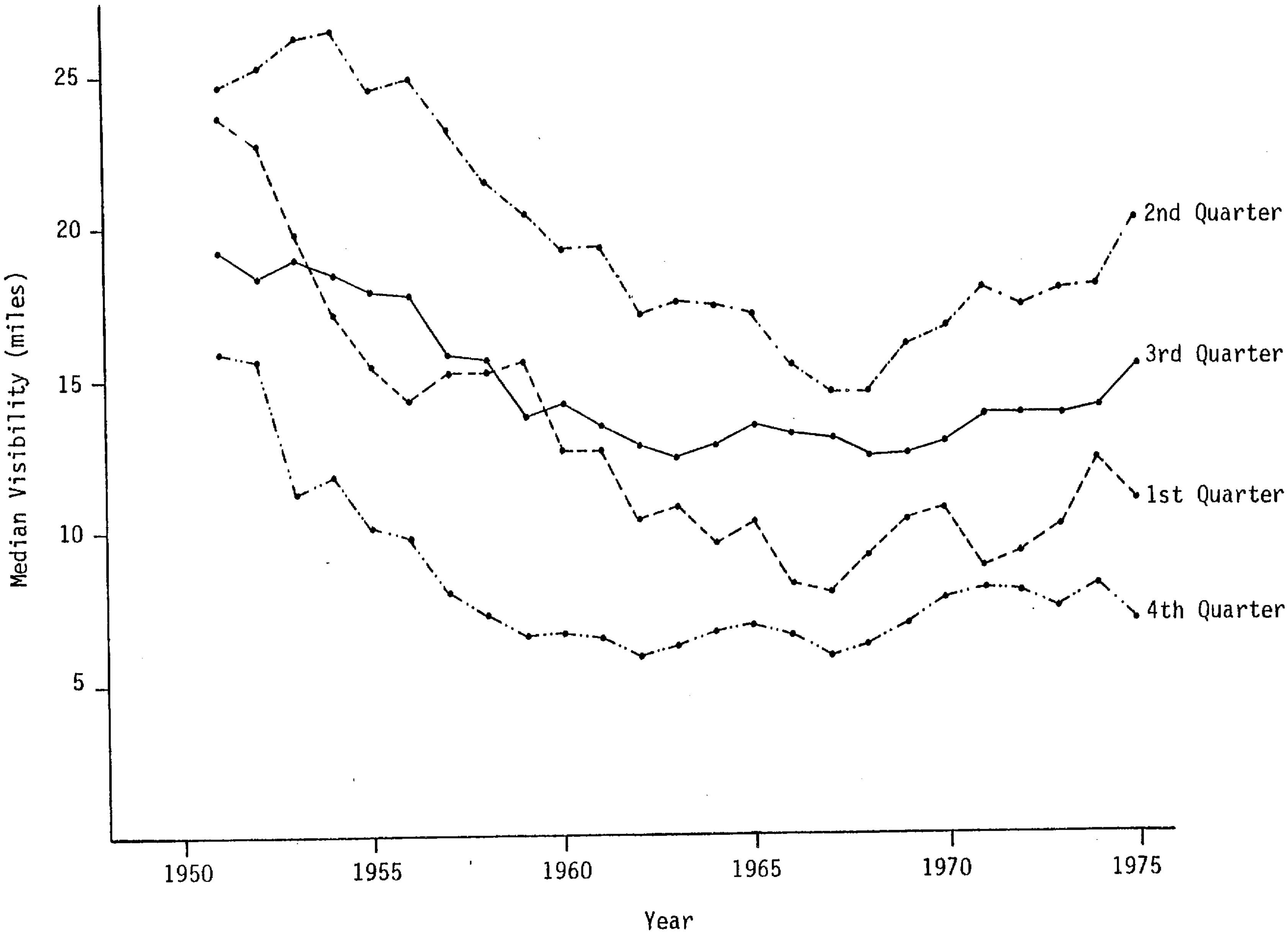

Figure 7.8 Long-term seasonal visibility trends in the San Joaquin Valley, 3-year moving averages of median visibility, mean of Bakersfield and Fresno.

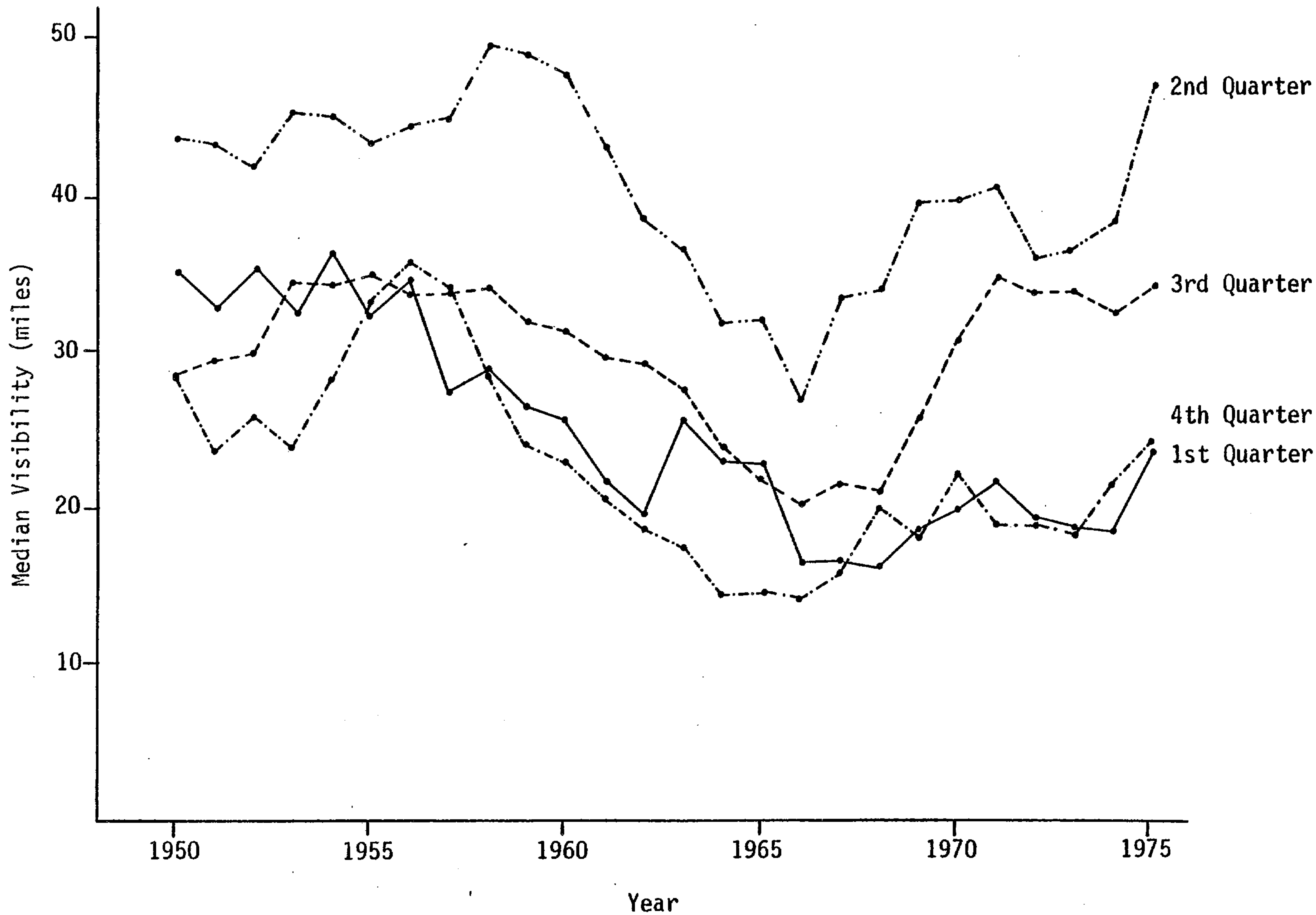

Figure 7.9 Long-term seasonal visibility trends in the Sacramento Valley, 3-year moving averages of median visibilities, mean of Red Bluff and Sacramento.

7.4 METEOROLOGICALLY STRATIFIED VISIBILITY TRENDS

As discussed in Section 2.3.2, the meteorological stratification scheme used in this report involves four weather classes:

Class I: fog, precipitation, blowing dust/snow, or wind speed > 12 knots.

Class II: non-Class I and relative humidity < 40%.

Class III: non-Class I and 40% ≤ relative humidity < 70%.

Class IV: non-Class I and 70% ≤ relative humidity.

For investigating meteorologically sorted visibility trends, we decided to use two of these classes, Class II and Class III. These two classes should be the ones that are least affected by natural causes of visibility reduction.

Tables 7.9 through 7.11 indicate net percent changes in median visibility, for all data as well as meteorologically stratified data, for the period 1949-1951 to 1965-1967, 1965-1967 to 1974-1976, and 1949-1951 to 1974-1976, respectively. These tables indicate that, with very few exceptions (e.g. Met-Class III at Yuma during 1949-1951 to 1965-1967, Met-Class II at Long Beach from 1965-1967 to 1974-1976, and Met-Class II at San Bernardino from 1965-1967 to 1974-1976), the trends in meteorologically stratified data parallel the trends in all the data fairly closely. This implies that the historical visibility changes most likely represent air quality changes rather than purely meteorological phenomena such as fog, precipitation, blowing dust/snow, or relative humidity. In particular, Tables 7.9 and 7.10 apparently indicate that the general tendencies of deteriorating visibility from 1949-1951 to 1965-1967 and improving visilbility from 1965-1967 to 1974-1976 are basically related to air quality changes rather than meteorological changes. Specifically, the deterioration prior to 1966 may be related to emission source growth, while the improvement after 1966 may be related to emission control programs.

As a caveat to the above paragraph, it should be noted that our meteorological classification scheme does not completely segregate meteorological and natural phenomena from man-related air quality phenomena. For example, it is possible that some of the historical visibility trends are due to air quality changes produced by natural emission sources rather than

TABLE 7.9 NET PERCENT CHANGES IN METEOROLOGICALLY SORTED VISIBILITY DATA, 1949-1951 TO 1965-1967.

AIR BASIN/LOCATION	CHANGES IN MEDIAN VISIBILITY		
	All Data	Meteorological Class II	Meteorological Class III
SOUTH COAST AIR BASIN			
Long Beach	+22%	+33%	+ 8%
San Bernardino[†]	-38%	-35%	-31%
San Nicolas[*]	+ 2%	ID	- 3%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield[†]	-30%	-28%	-31%
Oakland[†]	+22%	ID	+27%
San Francisco Int.	+ 6%	ID	+14%
OTHER COASTAL LOCATIONS			
Arcata[†*]	-24%	ID	+19%
San Diego	-28%	NC	-24%
Santa Maria[†]	-44%	ID	-43%
SAN JOAQUIN VALLEY AND SOUTHERN SCARAMENTO VALLEY AIR BASIN			
Bakersfield[*]	-48%	-36%	-48%
Fresno[†]	-41%	-42%	-47%
Sacramento	-19%	- 3%	-13%
Stockton	IP	IP	IP
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop[†a]	+ 7%	+14%	+ 7%
Burns[†b]	- 1%	+ 3%	- 4%
Medford	-12%	-14%	-12%
Red Bluff	-49%	-31%	-58%
SOUTHEAST DESERT AIR BASIN AND WESTERN ARIZONA			
Yuma[†]	-19%	-22%	+ 4%

[†]Percent changes are extrapolated based on data covering some, but not all, of the period in question.

[*]Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

ID = Insufficient data (less than 100 data points per year in this meteorological class).

IP = Insufficient period of data to estimate net percent changes in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

TABLE 7.10 NET PERCENT CHANGES IN METEOROLOGICALLY SORTED VISIBILITY DATA, 1965-1967 TO 1974-1976.

AIR BASIN/LOCATION	CHANGES IN MEDIAN VISIBILITY		
	All Data	Meteorological Class II	Meteorological Class III
SOUTH COAST AIR BASIN			
Long Beach	+26%	+54%	+31%
San Bernardino[†]	+16%	+85%	+10%
San Nicolas*	+14%	ID	+14%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield[†]	+54%	+76%	+71%
Oakland[†]	+ 9%	ID	+12%
San Francisco Int.	+ 2%	ID	+ 2%
OTHER COASTAL LOCATIONS			
Arcata*	+27%	ID	+27%
San Diego	IP	IP	IP
Santa Maria[†]	+29%	ID	+39%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN			
Bakersfield	+21%	+29%	+27%
Fresno	+14%	+28%	+12%
Sacramento	- 3%	-11%	-11%
Stockton	0%	+ 3%	- 1%
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop[a]	+23%	NC	+27%
Burns[b]	+ 6%	NC	+ 5%
Medford	+29%	+24%	+30%
Red Bluff	+122%	+79%	+121%
SOUTHEAST DESERT AIR BASIN AND WESTERN AIRZONA			
Yuma	+ 3%	+ 4%	- 2%

[†]Percent changes are extrapolated based on data covering some, but not all, of the period in question.

*Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

ID = Insufficient data (less than 100 data points per year in this meteorological class).

IP = Insufficient period of data to estimate net percent changes in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

TABLE 7.11 NET PERCENT CHANGES IN METEOROLOGICALLY SORTED VISIBILITY DATA, 1949-1951 TO 1974-1976.

AIR BASIN/LOCATION	CHANGES IN MEDIAN VISIBILITY		
	All Data	Meteorological Class II	Meteorological Class III
SOUTH COAST AIR BASIN			
Long Beach	+54%	+105%	+42%
San Bernardino[†]	-28%	+21%	-24%
San Nicolas[*]	+16%	ID	+11%
SAN FRANCISCO BAY AREA AIR BASIN			
Fairfield[†]	+ 8%	+27%	+19%
Oakland[†]	+33%	ID	+42%
San Francisco Int.[*]	+ 8%	ID	+17%
OTHER COASTAL LOCATIONS			
Arcata[†*]	- 3%	ID	+ 2%
San Diego	IP	IP	IP
Santa Maria[†]	-28%	ID	-21%
SAN JOAQUIN VALLEY AND SOUTHERN SACRAMENTO VALLEY AIR BASIN			
Bakersfield[*]	-37%	-17%	-34%
Fresno[†]	-33%	-25%	-41%
Sacramento	-21%	-14%	-22%
Stockton	IP	IP	IP
NORTHEASTERN CALIFORNIA AND SOUTHERN OREGON			
Bishop[†a]	+32%	NC	+35%
Burns[†b]	+ 5%	NC	+ 1%
Medford	+14%	+ 7%	+14%
Red Bluff	+13%	+24%	- 6%
SOUTHEAST DESERT AIR BASIN AND WESTERN AIRZONA			
Yuma[†]	-17%	-19%	+ 2%

[†]Percent changes are extrapolated based on data covering some, but not all, of the period in question.

[*]Trends for this period at these locations are possibly affected by reporting changes and/or site relocations.

[a]80th percentile rather than median.

[b]60th percentile rather than median.

ID = Insufficient data (less than 100 data points per year in this meteorological class).

IP = Insufficient period of data to estimate net percent changes in visibility.

NC = Not calculated because excessive extrapolation of the frequency distribution would be required.

man-made emission sources, or to meteorological factors that are not reflected in our meteorological indices. Nevertheless, the basic agreement between overall visibility changes and meteorologically sorted visibility changes suggests that the historical visibility trends are mostly due to man-made air quality trends. To confirm this conclusion, a comprehensive study of historical emission changes throughout California would be necessary.

As discussed in Section 7.3, the one outstanding seasonal feature in the visibility trend data for California is the deterioration of winter/fall visibility relative to spring/summer visibility in the San Joaquin and Sacramento Valleys. It is of interest to determine whether this seasonal feature is also apparent in the meteorologically stratified data. Table 7.12 summarizes visibility trends in the San Joaquin and Sacramento Valleys by season from 1949-1951 to 1974-1976 for both the entire data set and the meteorologically sorted data. It is obvious from the table that the meteorologically sorted data exhibit the same decline in winter/fall visibility relative to summer/spring visibility as do the unsorted data. This suggests that the strong seasonal features of historical visibility trends in the Central Valley are likely due to corresponding seasonal features in air quality trends.

7.5 DISCUSSION OF VISIBILITY TRENDS

This section summarizes our findings regarding historical visibility trends in California and discusses some of the potential causes for the visibility trends. The discussion is organized according to major geographical areas of California. At a few locations which have long-term NASN particulate data (for $\geq$ 10 years), the historical visibility changes are compared to ambient aerosol trends. In this section, we also compare our results to other recently published visibility trend studies for the South Coast Air Basin and Central Valley.

7.5.1 South Coast Air Basin (SCAB)

From 1950 to 1966,* the three coastal locations in the South Coast Air Basin (Downtown Los Angeles, Long Beach, and San Nicolas) displayed mixed

*For the sake of brevity, the 3-year periods 1949-1951, 1965-1967, and 1974-1976 will be denoted by the mid-years (1950, 1966, and 1975) throughout this section.

TABLE 7.12 NET PERCENT CHANGES IN SEASONAL VISIBILITY FOR THE SAN JOAQUIN AND SACRAMENTO VALLEYS FROM 1949-1951 TO 1974-1976, ALL DATA AND METEOROLOGICALLY SORTED DATA.

LOCATION/DATA SORT		CHANGES IN SEASONAL VISIBILITIES, 1949-1951 TO 1974-1976			
		1st Quarter Winter	2nd Quarter Spring	3rd Quarter Summer	4th Quarter Fall
Bakersfield*	All Data	-45%	- 8%	-25%	-60%
	Met-Class II	-15%	- 5%	-10%	-56%
	Met-Class III	-46%	- 6%	-29%	-56%
Fresno†	All Data	-59%	-29%	-16%	-60%
	Met-Class II	-52%	-27%	-10%	-56%
	Met-Class III	-63%	-32%	-21%	-58%
Sacramento	All Data	-40%	+ 2%	-17%	-26%
	Met-Class II	ID	-12%	-13%	-18%
	Met-Class III	-46%	- 9%	-12%	-36%
Red Bluff	All Data	-32%	+14%	+36%	-12%
	Met Class II	NC	NC	NC	NC
	Met-Class III	-14%	+36%	+31%	-20%

†Percent changes are extrapolated from data covering 1950-1952 to 1974-1976.

*Trends at this location are possibly affected by reporting changes and/or site relocation.

ID = Insufficient data (less than 25 data points per quarter).

NC = Not calculated because excessive extrapolation of frequency distribution would be required.

trends in visibility, anywhere from moderate ($\sim$20%) decreases to moderate increases in visibility depending on the site and visibility parameters (see Table 7.3). Following the more typical trend pattern in California from 1950 to 1966, the inland location (San Bernardino) exhibited a moderate to strong (30-40%) deterioration in visibility. From 1966 to 1975, all four SCAB locations experienced moderate to strong ($\sim$20-40%) increases in visibility (see Table 7.4). The net result for the period 1949 to 1975 was moderate improvement in visibility for the coastal area and moderate deterioration for the inland area (see Table 7.5).

There are no strong and consistent seasonal themes in the visibility trends for the SCAB (see Tables 7.6 to 7.8). The meteorologically stratified annual trends (Tables 7.9 to 7.11) agree fairly well with the raw trend data, suggesting that the visibility changes probably reflect air quality changes.

The visibility/aerosol analysis of Chapter 6 (see Table 6.11) indicates that sulfates, nitrates,* and the remainder of TSP all contribute significantly to visibility reduction in the SCAB, with sulfates being somewhat more important than the other two aerosol parameters. Accordingly, it is of interest to compare the historical trends in visibility to historical trends in sulfates, nitrates, and remainder of TSP. Unfortunately, there are at least three problems in using NASN particulate data for long-term trend analysis: (1) the NASN data do not provide a robust data set for trend studies (only about 25 days per year of sampling); (2) trends in the NASN nitrate data may be significantly affected if undocumented changes occurred in the filters used for Hi-Vol sampling (Cass 1980); and (3) the NASN laboratory techniques for determining sulfate and nitrate were changed at the end of 1965. Despite these problems, we have compared long-term trends in extinction (24.3 ÷ visibility) at Downtown Los Angeles** and Long Beach to corresponding trends

*As noted previously in this report, because of measurement difficulties associated with nitrates, it is best to regard the "nitrate" variable as being a gross measure of both nitrate aerosol and other related photochemical pollutants (such as secondary organic aerosols and NO_2).

**Note that a slight adjustment (based on Table 7.1) is applied to the Downtown Los Angeles data in Figure 7.10 to account for the site relocation in 1964.

in NASN aerosol data (see Figure 7.10). It is difficult to read obvious cause-and-effect relationships from Figure 7.10; however, the extinction trends are not inconsistent with the aerosol trends in the sense that the slight decreases in extinction from 1958 to 1974 could be accounted for by the net effect of the slight decrease in sulfates, the moderate increase in nitrates, and the strong decrease in the remainder of TSP.

Keith (1979b) examined historical visibility changes in the SCAB using as a trend index "the number of days per year that the daily minimum visibility was less than three miles at relative humidity less than seventy percent". Although Keith used a different type of trend index and focused on worst-case days, his findings are very similar to ours. Keith showed that visibility at four locations in the coastal part of the SCAB (Burbank, Downtown Los Angeles, Long Beach, and Los Angeles International Airport) experienced moderate to strong improvements in visibility from 1950 to 1977, with most of the improvement occurring from the mid-1960's to the mid-1970's. He also found that visibility in the inland area (Ontario, Riverside, and San Bernardino) displayed slight to moderate deterioration from 1950 to 1977, with most of the deterioration occurring from the early 1950's to the middle 1960's. Keith attributed the spatial differences in the trends to two factors: (1) higher growth rates for sources in the eastern-inland region and in areas (i.e. Orange County) upwind of the eastern-inland region, and (2) the historical control strategy of reducing hydrocarbon emissions while increasing NO_x emissions, which decreased the HC/NO_x ratio, delayed the formation of photochemical smog, and shifted photochemical smog downwind (inland) from the coastal areas.

7.5.2 San Francisco Bay Area Air Basin (SFBAAB)

From 1950 to 1966, the two coastal sites in the SFBAAB (San Francisco International and Oakland) exhibited moderate ($\sim$20%) improvements in visibility, while the inland site (Fairfield) displayed a moderate to strong ($\sim$30 to 40%) decline in visibility. From 1966 to 1975, the coastal sites underwent further slight increases in visibility, while Fairfield reversed its previous trend and showed a strong ($\sim$50%) increase in visibility. Over the entire period 1950 to 1975, the net result was moderate to strong

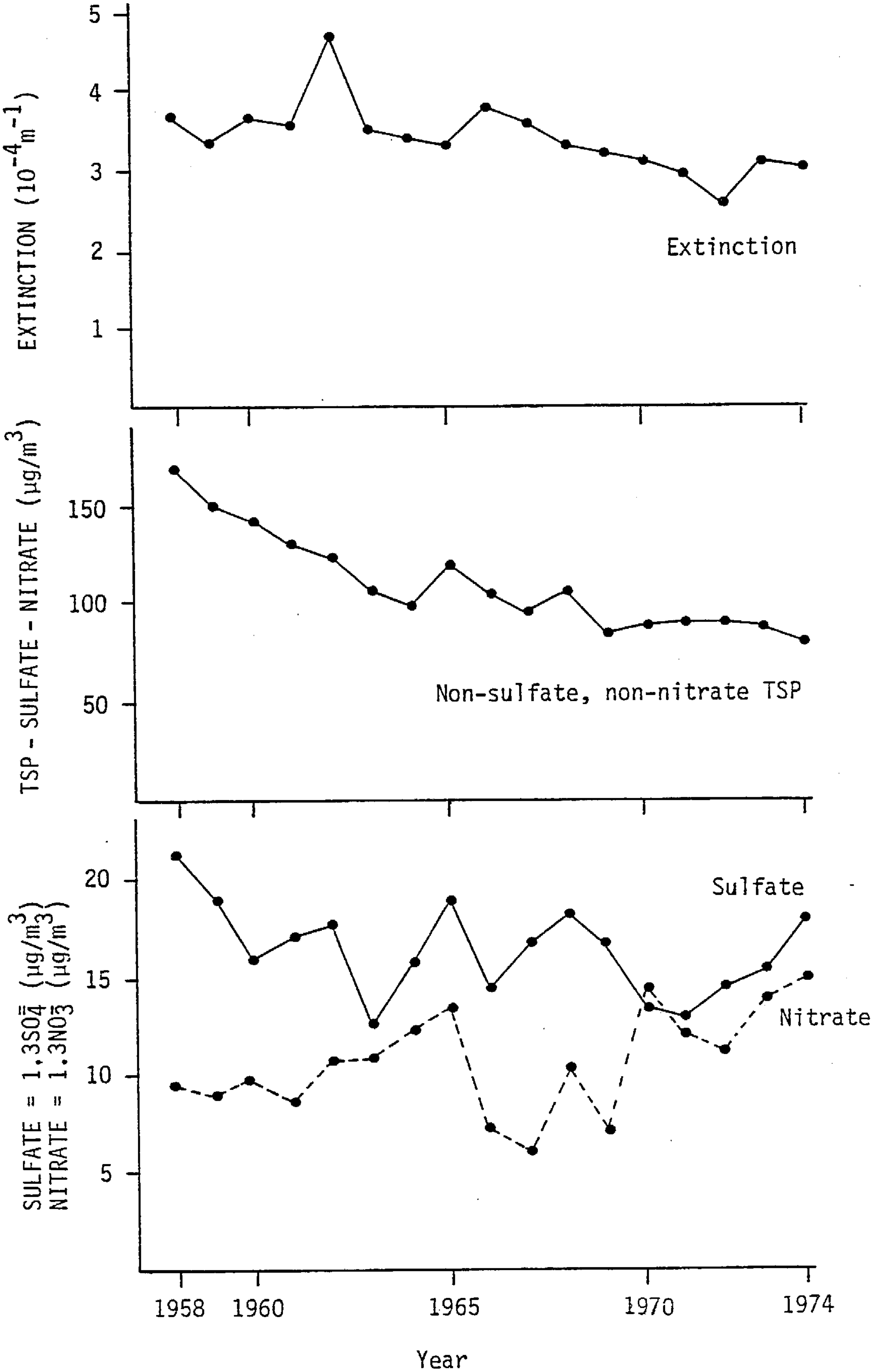

Figure 7.10 Yearly trends in extinction compared to yearly trends in aerosol concentrations from 1958 to 1974, average of Downtown Los Angeles and Long Beach.

($\sim$30 to 40%) increases in visibility for the coastal sites and little change at the inland location. It is interesting to note that the spatial variations in the visibility trends for the SFBAAB are similar to the spatial variations for the South Coast Air Basin.

There are no outstanding seasonal features in the long-term visibility trends for the SFBAAB. The meteorologically adjusted annual visibility trends closely resemble the raw annual trends, indicating that the historical visibility changes are likely the result of air quality changes rather than meteorological changes.

The results of Chapter 6 suggest that sulfates, nitrates, and the remainder of TSP all contribute about equally to extinction in the SFBAAB. Figure 7.11 compares long-term trends in extinction at Oakland* and San Francisco to long-term trends in NASN data for sulfates, nitrates, and the remainder of TSP. Although, as noted previously, the NASN particulate data are of limited use in long-term trend analysis, the extinction trends agree fairly well with the particulate trends; the moderate decline in extinction from 1958 to 1974 seems reasonable in light of the moderate decrease in sulfates, moderate increase in nitrates, and strong decrease in the remainder of TSP.

7.5.3 Other Coastal Locations

Other coastal locations in California (Arcata, San Diego, and Santa Maria) displayed moderate to strong ($\sim$20 to 40%) declines in visibility from 1950 to 1966. At the two sites with adequate data after 1966 (Arcata and Santa Maria), there were moderate ($\sim$20 to 30%) increases in visibility from 1966 to 1975. The result for the period 1950 to 1975 was no net change in visibility at Arcata and a slight to moderate ($\sim$ 10 to 20%) deterioration at Santa Maria.

No remarkable seasonal features exist in the historical visibility trends for Arcata, San Diego, and Santa Maria. The meteorologically stratified annual trends at all three locations parallel the raw trends very

*To account for the site relocation in 1965, a slight adjustment (based on Table 7.1) has been made in the Oakland extinction trends.

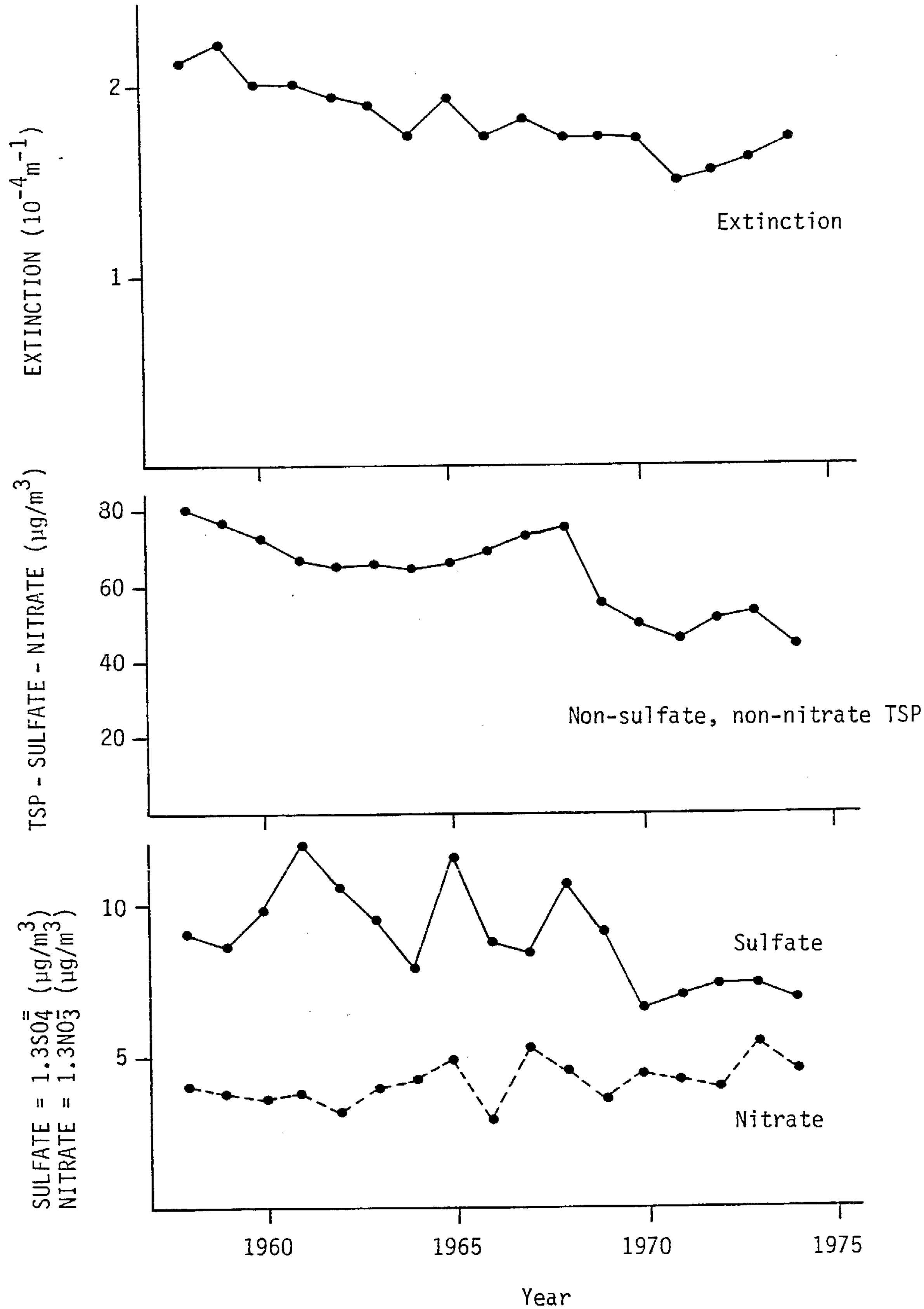

Figure 7.11 Yearly trends in extinction compared to yearly trends in aerosol concentrations from 1958 to 1974, average of Oakland and San Francisco.

closely; this suggests that air quality changes, rather than meteorological changes, are responsible for the visibility trends.

In Chapter 6 we analyzed visibility/aerosol relationships for one of the above three coastal locations -- San Diego. Our results indicate that sulfates account for approximately 50% of aerosol extinction at San Diego, with nitrates and the remainder of TSP each contributing about equally to the remaining 50%. Figure 7.12 compares extinction trends at San Diego to aerosol trends for the period 1958 to 1968 (the visibility data are not suitable for trend analysis beyond 1968). Extinction displays little net change from 1958 to 1968; this is reasonable in the sense that sulfates increased very slightly, nitrates showed no net change, and TSP decreased moderately. It is also interesting that sulfates and extinction both exhibit a pronounced peak in 1962.

7.5.4 San Joaquin Valley and Sacramento Valley Air Basins (Central Valley)

From 1950 to 1966, three sites in the Central Valley (Bakersfield, Fresno, and Red Bluff*) underwent strong ($\sim$40 to 50%) deterioration in visibility, and a fourth site (Sacramento) experienced a moderate ($\sim$20%) decline in visibility. From 1966 to 1975, Red Bluff displayed a strong ($\sim$50 to 100%) improvement in visibility; Bakersfield and Fresno showed slight to moderate ($\sim$10 to 20%) improvements; while Stockton and Sacramento exhibited little change. The net effects for the period 1950 to 1975 were moderate to strong ($\sim$30 to 40%) visibility decreases at Bakersfield and Fresno, a moderate ($\sim$20%) decrease at Sacramento, and little change at Red Bluff.

There is a very remarkable seasonal feature in the historical visibility changes for the Central Valley. From 1950 to 1975, Bakersfield, Fresno,

*In previous figures and tables of this chapter, we grouped Red Bluff with sites in the area "northeastern California and southern Oregon", because Red Bluff was located closer to those sites, and because average visibility at Red Bluff ($\sim$50 miles) was similar to average visibility at those sites. However, the historical visibility <u>changes</u> at Red Bluff parallel the changes at other locations in the Central Valley; therefore Red Bluff is discussed here with the Central Valley sites rather than in the next section.

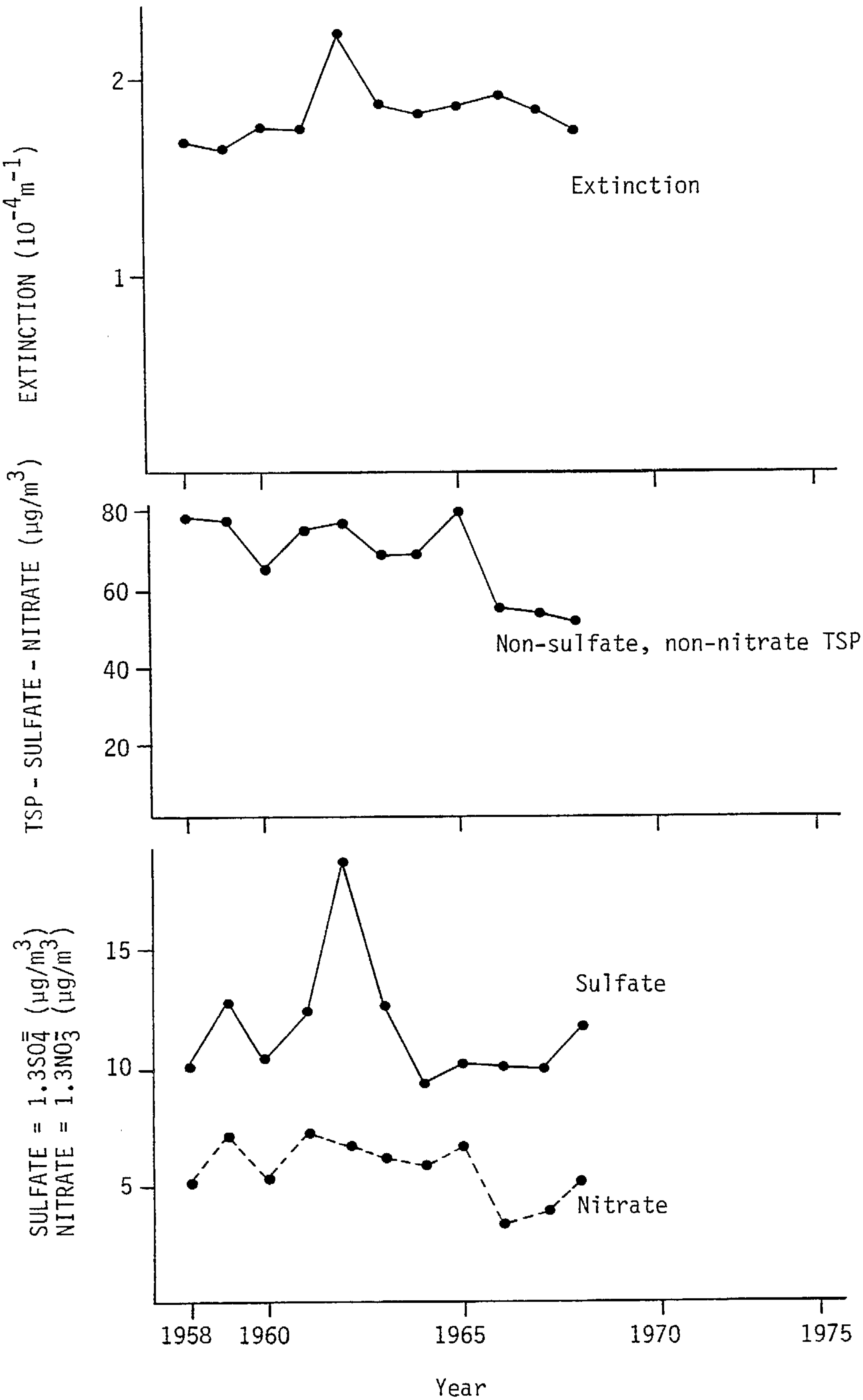

Figure 7.12 Yearly trends in extinction compared to yearly trends in aerosol concentrations from 1958 to 1968 at San Diego.

Red Bluff, and Sacramento all showed strong declines in winter/fall visibility relative to spring/summer visibility.

All of the above trends in raw visibility data agree very closely with the trends in meteorologically sorted data for the Central Valley. This indicates that air quality changes, rather than weather changes, are probably responsible for the visibility trends. That man-made air quality trends are responsible for observed declines in visibility within the Central Valley is also implied by the seasonality of the visibility trends; the winter and fall seasons should be most sensitive to anthropogenic air quality changes (especially with respect to secondary aerosols) because the winter/fall period is the prime season for stagnant air and high relative humidity (which can promote secondary aerosol formation and accumulation), (NOAA 1977).

The visibility/aerosol analysis in Chapter 6 indicates that sulfates, nitrates, and the remainder of TSP each contribute about one-third of aerosol extinction in the Central Valley. There is only one location in the Central Valley, Sacramento, that has a sufficient period of NASN data to compare long-term trends in extinction with long-term particulate trends. As shown in Figure 7.13, the extinction trends for Sacramento from 1964 to 1974 seem readily explainable in terms of aerosol trends. From 1964 to 1971, extinction remained nearly constant as sulfates and nitrates increased slightly and the remainder of TSP decreased moderately. The upward jump in extinction from 1971 to 1974 mirrors a similar jump in sulfates and nitrates.

Duckworth and Kinney (1978) examined visibility trends in the Central Valley from 1958 to 1977, using as an index the frequency of 1:00 PM visibilities that are less than 10 miles when relative humidity is less than 70%. Duckworth and Kinney emphasized nearly the same time-period dichotomy in the trends that we have stressed. Before 1967, they found constant trends in summertime visibility (we found deteriorating trends in annual visibility before 1966). After 1967, they reported improving trends in summertime visibility (we reported improving trends in annual visibility after 1966). Duckworth and Kinney attributed the visibility improvements since 1967 to automotive controls (started in 1963 and continually tightened thereafter) and to controls on agricultural, backyard, and open-dump burning (started

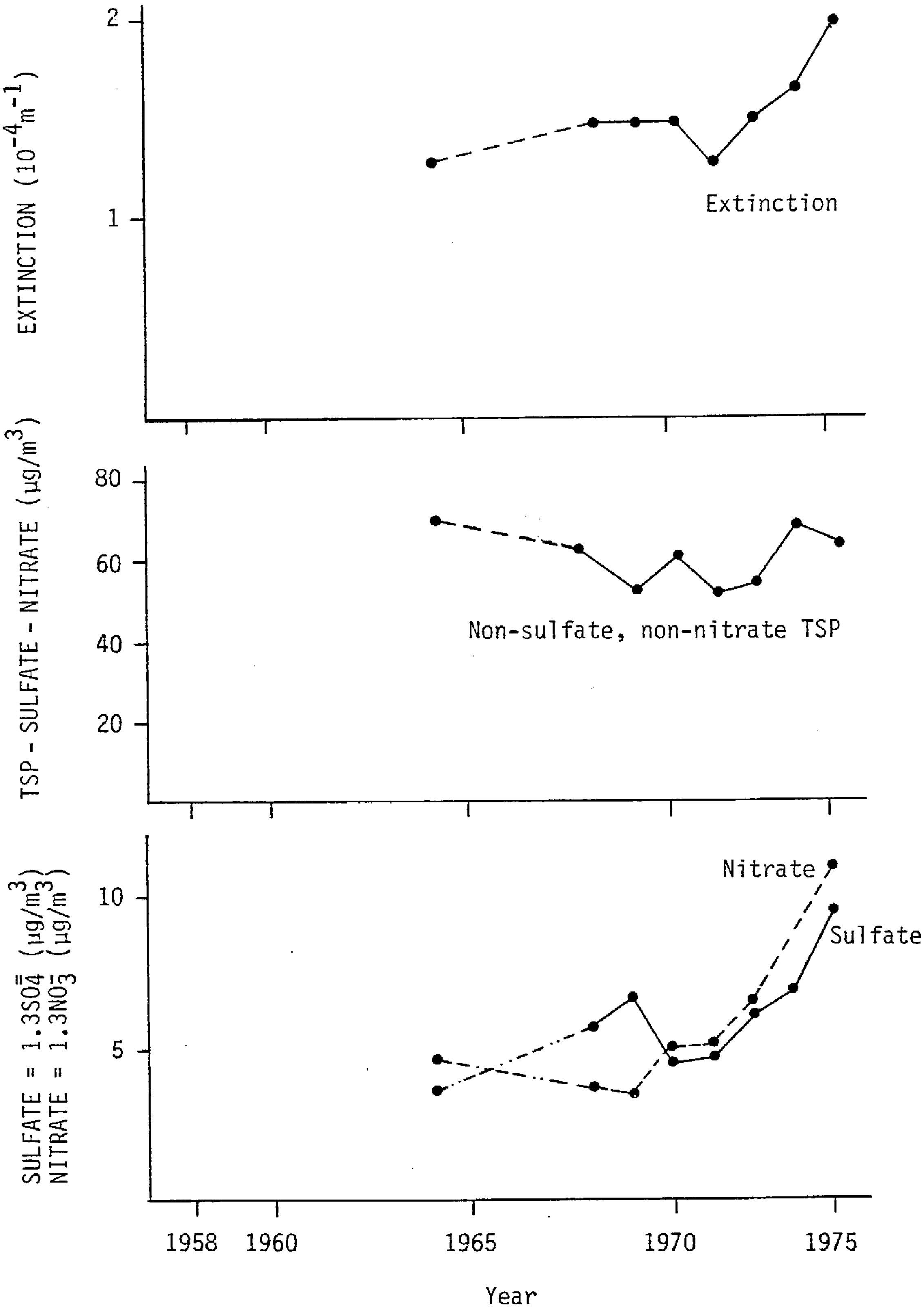

Figure 7.13 Yearly trends in extinction compared to yearly trends in aerosol concentrations from 1964 to 1974 at Sacramento.

in 1971). This is consistent with our conclusion that air quality changes, rather than meteorology, are responsible for the observed visibility trends in the Central Valley.

7.5.5 Northeastern California and Southern Oregon

Bishop CA, Burns OR, and Medford OR all exhibit very mild historical trends in visibility. From 1950 to 1966, Bishop and Burns underwent little change in visibility, while Medford experienced a slight ($\sim$10%) deterioration. From 1966 to 1975, all three sites displayed slight to moderate ($\sim$10 to 20%) increases in visibility. The net effects for the period 1950 to 1975 were slight improvements at Burns and Medford and a moderate improvement at Bishop.

The only notable seasonal feature in the trend data for these three sites occurs at Medford. Like the Central Valley locations, Medford exhibited a pronounced decline in winter/fall visibility relative to spring/summer visibility.

The meteorologically stratified trends at all three locations are very similar to the raw annual trends. This suggests that air quality variations rather than meteorological variations probably caused the observed visibility changes. The historical visibility changes at these three locations are so slight, however, that we cannot rule out minor meteorological shifts as the cause of the visibility changes.*

We have not completed visibility/aerosol regression analyses for any of these three locations, nor are any long-term trend data for aerosol concentrations available for comparison with the visibility trends. Thus, we cannot speculate on the specific air quality changes that may have caused the historical visibility changes.

7.5.6 Southeast Desert Air Basin and Western Arizona

There is only one location in the southeast desert, Yuma AZ, at which we have studied long-term visibility trends. Yuma exhibited a slight decline ($\sim$10%) in visibility from 1950 to 1966 and no change in visibility from 1966 to 1975. The net effect was a slight deterioration from 1950 to 1975.

*As discussed previously (Section 7.4), our meteorological classification scheme cannot completely segregate meteorological and natural phenomena from man-related air quality phenomena.

There is a minor seasonal aspect to the long-term visibility trends at Yuma. The deterioration in visibility from 1950 to 1977 was slightly greater in the spring/summer than it was during the winter/fall.

The annual trends for all the data at Yuma agree fairly well with the meteorologically adjusted trends. The agreement is particularly close for meteorological Class II (relative humidity $< 40\%$) which represents the preponderance of data ($\sim 75\%$ of all hours) at Yuma. This seems to indicate that the historical visibility changes are due to air quality variations rather than meteorology; the visibility changes are so slight, however, that we cannot rule out minor meteorological trends as the cause of the visibility changes.

Long-term NASN data are not available for comparing aerosol and visibility trends at Yuma. Also, we were not able to perform visibility/aerosol regression analyses at Yuma. The results of other studies, however, provide information about the causes of visibility reduction in the Rocky Mountain Southwest (Yuma lies on the southwest edge of that region). The consensus of these studies, based on regression models (Trijonis 1979) and mass balance of accumulation size-range aerosols (Macias et al. 1979, Pitchford 1980), indicates that approximately 50% of aerosol extinction (extinction above-and-beyond the blue-sky scatter by air molecules) is due to sulfates and approximately 30% is due to dust particles, with the remaining 20% not well characterized. In future work, it would be interesting to attempt an explanation for the visibility trends at Yuma in terms of historical changes in fugitive dust sources, transported sulfates from Los Angeles, and transported sulfates from the copper smelters in southeast Arizona.

7.5.7 Need for Emission Trend Analysis

As evidenced by the above discussions, it is difficult to reach firm conclusions regarding the causes of historical visibility trends without long-term data on pollutant trends. The NASN data on ambient aerosol trends are not of great help for interpreting visibility changes because NASN data cover a relatively short time period, because historical NASN data are available only for a few locations, and because serious statistical and measurement problems arise in using NASN data for long-term trend analysis (see discussion on page 174). The best possibility for documenting long-term ($\sim$ 30 year) pollutant trends is to conduct a study of historical emission trends for primary aerosols and for precursors of secondary aerosols (SO_x, NO_x, and hydrocarbons). No such emission trend study -- based on a consistent data base of uncontrolled emission factors, historical control factors, and source growth factors -- is available for California. Such a study should be possible*, however, and a detailed analysis of 30-year emission trends for various regions in California should be regarded as a promising area for future research.

7.6 EFFECTS OF HAZE ON CLIMATE

In a study of the eastern United States, Husar et al. (1979) reported climatic changes that seemed to follow trends in haziness. From the early 1950's to the early 1970's, shifts in temperature patterns occurred at certain rural locations in the East that had undergone substantial declines in visibility. At these locations there was little change in nighttime temperature but significant decreases in daytime temperature. It can be postulated that increases in light-scattering aerosols could cause this effect by scattering back incoming sunlight (i.e. acting as a partial cloud cover) while either reducing or having little effect on nocturnal heat radiation from the earth (Bolin and Charlson 1976).

Two eastern locations with large decreases in visibility and daytime temperature were Lexington, KY and Charlotte, NC. The changes observed at these locations from the middle 1950's to the early 1970's are summarized in Table 7.13. These results suggest that an increase in aerosol scattering of 1.0 $(10^4 m)^{-1}$, as measured by the visibility data, might lead to a decrease in mid-day temperature on the order of $3\frac{1}{2}$°F.

*That such a study can be performed is evidenced by the recent work of Marians and Trijonis (1979) who compiled year-by-year emission trends from 1949 to 1976 for 10 source categories, three pollutants (SO_x, NO_x, and hydrocarbons), and four states (Arizona, Colorado, Nevada, and Utah).

TABLE 7.13 HISTORICAL CHANGES IN VISIBILITY, EXTINCTION, AND TEMPERATURE AT LEXINGTON AND CHARLOTTE (Trijonis and Yuan 1978b).

LOCATION AND TIME PERIODS	AEROMETRIC CHANGES		
	Median Visibility (miles)	Median Extinction† $(10^4 m)^{-1}$	Average 1 PM Temperature (°F)
Lexington, KY 1953-1955 to 1970-1972	16.4 to 9.7	+1.02	-3.7
Charlotte, NC 1955-1957 to 1970-1972	14.8 to 10.0	+0.79	-2.7

†The change in median extinction is computed from the change in median visibility using the Koschmeider formula.

During various sub-periods of the years 1950 to 1975, many California locations have undergone large changes (either increases or decreases) in visibility. To investigate the hypothesis that haze trends in California affect climate, we have examined changes in extinction and daily maximum temperature, using the period of the largest visibility change at each site, and restricting the analysis to periods with no site relocations. For some sites we have examined two periods (one of decreasing visibility and one of increasing visibility). At each location, 3-year averages are used to quantify changes in median extinction and average daily maximum temperature. We only considered those sites and time periods over which there was at least a 0.2 $(10^4 m)^{-1}$ absolute change in median extinction.

The results of this analysis are listed in Table 7.14 and plotted in Figure 7.14. The points in Figure 7.14 reveal no relationship between historical extinction changes and historical temperature changes. Fitting a regression line to the points yields a correlation coefficient of 0.08 (insignificant) and a slope of 0.02 (also insignificant).*

*For our results to agree with the Lexington and Charlotte data, we would need a sizeable negative correlation coefficient and a slope on the order of -3.5 (°F)/$(10^4 m)^{-1}$.

TABLE 7.14 CHANGES IN HISTORICAL EXTINCTION LEVELS COMPARED TO CHANGES IN DAILY MAXIMUM TEMPERATURE.

LOCATION AND TIME PERIOD	AEROMETRIC CHANGES	
	Median Extinction $(10^4 m)^{-1}$	Daily Maximum Temperature (°F)
Long Beach 1960-1962 to 1974-1976	-1.0	+1.3
San Beranrdino 1959-1961 to 1965-1967	+0.6	-1.7
San Nicolas 1951-1953 to 1962-1964	+0.8	+1.0
San Nicolas 1962-1964 to 1972-1974	-0.9	+1.0
Fairfield 1957-1959 to 1963-1965	+0.4	-2.7
Fairfield 1963-1965 to 1968-1970	-0.3	+2.6
Oakland 1950-1952 to 1962-1964	-0.6	-0.9
San Francisco 1956-1958 to 1971-1973	-0.4	-2.2
Arcata 1950-1951 to 1958-1960	+0.8	+2.4
Arcata 1958-1960 to 1974-1976	-0.8	-0.3
San Diego 1949-1951 to 1962-1964	+0.6	+0.4
Santa Maria 1955-1957 to 1967-1969	+0.7	+1.9
Bakersfield 1959-1961 to 1966-1968	+0.4	-0.1
Bakersfield 1966-1968 to 1974-1976	-0.5	+1.5
Fresno 1950-1952 to 1958-1960	+0.4	+0.5
Fresno 1965-1967 to 1974-1976	-0.2	-0.8
Sacramento 1957-1959 to 1965-1967	+0.4	-1.3
Sacramento 1965-1967 to 1969-1971	-0.4	+0.4
Sacramento 1969-1971 to 1974-1976	+0.5	+0.8
Medford 1954-1956 to 1965-1967	+0.3	+2.1
Red Bluff 1955-1957 to 1965-1967	+0.6	+1.3
Red Bluff 1965-1967 to 1974-1976	-0.6	-0.3

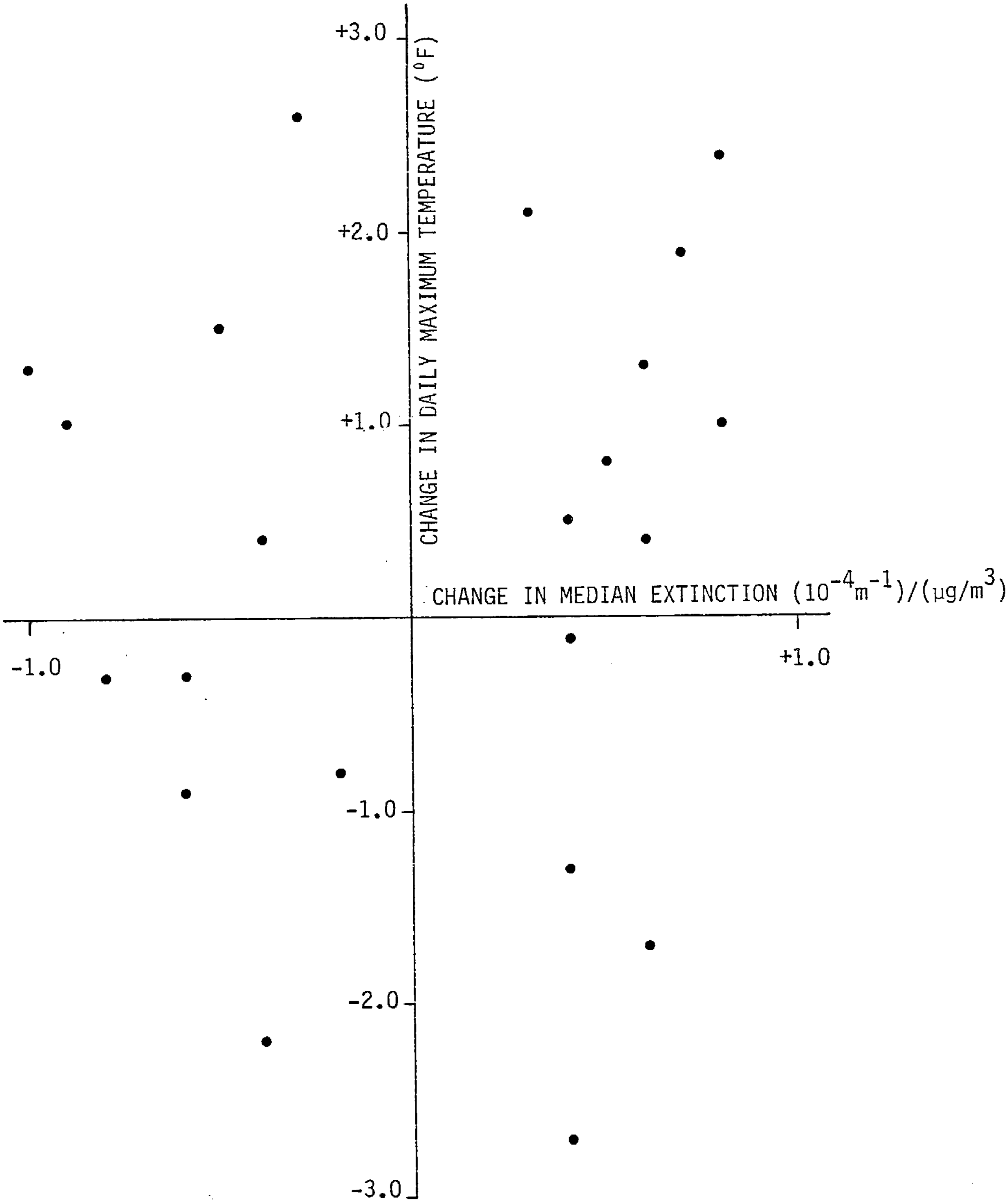

Figure 7.14 Scatterplot of historical changes in daily maximum temperature versus historical changes in extinction coefficient.

The effects of haze on temperature might be masked by natural temperature trends or by variations in urban heat islands. In an attempt to partially discount for these factors, we compared changes in maximum minus minimum temperature with changes in extinction using the same sites and periods listed in Table 7.14. (As noted earlier, increased haziness from light-scattering aerosols should theoretically reduce daily maximal temperature relative to daily minimum temperature.) Again, we found no statistically significant relationship.

The above results do not prove conclusively that haze levels exert little effect on temperature in California. The relationship between light-scattering and temperature might be concealed by natural temperature cycles, changes in urban heat islands, or changes in the absorption component of haze. Our results do suggest, however, that the relationship between haze and temperature is not as strong or as obvious as one might have suspected based on the data for Lexington and Charlotte.

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APPENDIX A

List of Weather Stations in California

TABLE A.1 WEATHER STATIONS IN CALIFORNIA OPERATING DURING 1976.

YEAR	NAME	TYPE	LAT.	LONG.	ELEV.	J	F	M	A	M	J	J	A	S	O	N	D	SYNOPTIC FORM	METL SUMMARY	BAROGRAMS	THERMOGRAMS	TRIPLE REGISTER	WIND RECORDER	HUMIDITY RECORDER	RADAR LOGS	WBAN NUMBER
						HOURLY RECORDS BY MONTH, 1 = 24 OBS PER DAY												NUMBER OF MONTHS IN YEAR WITH								
1976	ALAMEDA	NAS	37 44N	122 19W	30	1	1	1	1	1	1	1	1	1	1	1	1			02	06		06			23239
	ANACAPA IS	CG	34 01N	119 22W	139	3	3	3	3	3	3	3	3	3	3	3	3									
	ARCATA	FAA	40 59N	124 06W	228	1	1	1	1	1	1	1	1	1	1	1	1			12						24283
	BAKERSFIELD	WSO	35 25N	119 03W	497	1	1	1	1	1	1	1	1	1	1	1	1			12			09			23155
	BEALE	AFB	39 08N	121 26W	126	1	1	1	1	1	1	1	1	1	1	1	1									93216
	BEAUMONT	A	33 56N	116 57W	2600	5	5	5	5	5	5	5	5	5	5	5	5									23156
	BISHOP	WSO	37 22N	118 22W	4112	6	6	6	6	6	6	6	6	6	6	6	6			12	12		12			23157
	BLUE CANYON	WSO	39 17N	120 42W	5283	5	5	5	5	5	5	5	5	5	5	5	5			12	12					23225
	BLYTHE	FAA	33 37N	114 43W	395	1	1	1	1	1	1	1	1	1	1	1	1			11						23158
	BODEGA BAY	CG	38 19N	123 03W	10	5	5	5	5	5	5	5	5	5	5	5	5									
	BURBANK	FAA	34 12N	118 22W	742	1	1	1	1	1	1	1	1	1	1	1	1									23152
	BURNEY	A	40 53N	121 40W	3142	3	3	3	3	3	3	3	3	3	3	3	3									24212
	CABRILLO	CG	33 43N	118 17W	25								3	3	3	3	3									
	CAMP PENDELT	MCAS	33 18N	117 21W	66	5	5	5	5	5	5	6	6	6	6	6	5			12			11	03		03154
	CAMPO	A	32 37N	116 28W	2630	5	5	5	5	5	5	5	5	5	5	5	5									
	CARLSBAD	A	33 08N	117 17W	328	1	1	1	1	1	1	1	1	1	1	1	1									
	CASTLE	AFB	37 22N	120 34W	197	1	1	1	1	1	1	1	1	1	1	1	1									23203
	CASTROVILLE	CG	36 48N	121 48W	18	5	5	5	5																	
	CATALINA APT	A	33 24N	118 25W	1580	6	6	6	6	6	6	6	6	6	6	6	6									
	CHANNEL IS	CG	34 10N	119 13W	12	3	3	3	3	3	3	3	3	3	3	3	3									
	CHICO	SAWR	39 48N	121 51W	237	6	6	6	6	6	6	6	6	6	6	6	8									93203
	CHINO	LAWR	33 58N	117 38W	695	8	6	6	6	6	6	6	6	6	6	6	6									
	CONCORD	CG	38 02N	122 02W	10						5	5	5	5	5	5	5									
	CONCORD	FAA	37 59N	122 03W	60	6	6	6	6	8	6	6	6	6	6	6	6									23254
	CRESCENT CTY	FAA	41 47N	124 14W	56	7	7	7	7	7	7	7	7	7	7	7	7			12						24286
	CROWS LANDIN	NAS	37 24N	121 08W	165	5	5	5	5	5	5	5	5	5	5	5	5									23240
	CUDDEBACK	AFB	35 16N	117 26W	2835	6	6	6	6	6	6	6	6	6	6	6	6									03147
	DAGGETT	FSS	34 52N	116 47W	1929	1	1	1	1	1	1	1	1	1	1	1	1			12						23161
	DAVIS POINT	CG	38 03N	122 16W	60	5	5	5	5	5	5	5	5	5	5	5	5									
	EDWARDS	AFB	34 55N	117 54W	2316	6	6	6	6	6	6	6	6	6	6	6	6									23114
	EL MONTE	LAWR	34 08N	118 02W	333	6	6	6	6	6	6	6	6	6	6	6	6									
	EL MONTE	SAWR	34 05N	118 02W	295								3													
	EL TORO	MCAS	33 40N	117 44W	380	1	1	1	1	1	1	1	1	1	1	1	1			11	01		08			93101
	EUREKA	WBO	40 48N	124 10W	79														12	12	02	12	10			24213
	FORT ORD	AAF	36 41N	121 46W	140	6	6	6	6	6	6	8	6	6	6	6	6									93217
	FRESNO	LAWR	36 44N	119 49W	277	6	6	6	6	6	6	6	6	6	6	6	6									
	FRESNO AIR T	WSO	36 46N	119 43W	330	1	1	1	1	1	1	1	1	1	1	1	1			12		12	12			93193
	FULLERTON	FAA	33 52N	117 58W	99	6	6	6	6	6	8	8	6	6	6	6	6									
	GEORGE	AFB	34 35N	117 23W	2849	1	1	1	1	1	1	1	1	1	1	1	1									23131
	HAWTHORNE	LAWR	33 55N	118 20W	63	6	6	6	8	8	6	6	8	6	6	6	6									
	HAYWARD	LAWR	37 39N	122 07W	29	6	6	6	6	6	6	6	6	6	6	6	6									
	HERMOSA BCH	CG	33 52N	118 24W	25									4	4	4	4									
	HUMBOLOT BAY	CG	40 46N	124 14W	10	5	5	5	5	5	5	5	5	5	5	5	5									24263
	HUNTINGTON B	CG	33 39N	118 00W	118	3	3	3	3	3	3	3	3	3	3	3	3									
	IMPERIAL	FAA	32 50N	115 34W	-56	1	1	1	1	1	1	1	1	1	1	1	1			12						03144
	IMPERIAL BCH	NAS	32 34N	117 07W	21	6	6	6	6	6	6	6	6	6	6	6	6			12	10		12			93115
	INYOKERN	SAWR	35 40N	117 50W	2426	3	3	3	3	3	3	3	3	3	3	7	3									93194
	INYOKERN	NAF	35 41N	117 41W	2238	6	6	6	6	6	6	6	6	6	6	6	6			12						93104
	LAKE TAHOE	CG	39 11N	120 07W	6233	3																				
	LANCASTER	SAWR	34 44N	118 13W	2347	1	1	1	1	1	1	1	1	1	1	1	1			12						03159
	LAVERNE	LAWR	34 08N	117 47W	1000	8	6	6	6	6	6	6	6	6	6	6	6									
	LEMOORE	NAS	36 20N	119 57W	238	1	1	1	1	1	1	1	1	1	1	1	1			12	01		09			23110
	LIVERMORE	LAWR	37 42N	121 49W	397	6	6	6	6	6	6	6	6	6	6	6	6									
	LONG BEACH	WSO	33 49N	118 09W	68	1	1	1	1	1	1	1	1	1	1	1	1			12			12			23129
	LOS ANGELES	WSO	33 56N	118 24W	110	1	1	1	1	1	1	1	1	1	1	1	1			12			10			23174
	LOS ANGELES	COOP	34 02N	118 14W	257																	12				
	MAMMOTH LAKE	SAWR	37 38N	118 51W	7128	5	5	5	5	5	3	3	3		3	3	3									
	MAR DEL REY	CG	33 58N	118 27W	10	3	3	3	3	3	3	3	3	3	3	3	3									
	MARCH	AFB	33 53N	117 15W	1514	1	1	1	1	1	1	1	1	1	1	1	1									23119
	MARYSVILLE	FAA	39 06N	121 34W	72	1	1	1	1	1	1	1	1	1	1	1	1			12						93205
	MATHER	AFB	38 34N	121 18W	131	1	1	1	1	1	1	1	1	1	1	1	1									23206
	MCCLELLAN	AFB	38 40N	121 24W	82	1	1	1	1	1	1	1	1	1	1	1	1									23208
	MERCED	SAWR	37 17N	120 31W	152	5	5	5	5	5	5	5	5	5	5	5	5									23257
	MIRAMAR	NAS	32 52N	117 08W	459	1	1	1	1	1	1	1	1	1	1	1	1			10	07		10			93107
	MISSION BAY	CG	32 45N	117 14W		3	3	3					3	3												
	MODESTO	SAWR	37 38N	120 57W	140	6	6	6	6	6	6	6	6	6	6	6	6									23258
	MOFFETT FLD	NAS	37 25N	122 03W	39	1	1	1	1	1	1	1	1	1	1	1	1			12	12		12			23244
	MONTAGUE	FSS	41 47N	122 28W	2841	6	6	6	6	6	6	6	6	6	6	6	6									24259
	MONTEREY	FAA	36 35N	121 51W	165	1	1	1	1	1	1	1	1	1	1	1	1									
	MT SHASTA	WBO	41 19N	122 13W	3550	5	5	5	5	5	5	5	5	5	5	5	5			12						24215
	MT WILSON	SA	34 14N	118 04W	5710	3	3	3	3	3	3	3	3	3	3	3	3			12	12					93136
	NAPA	LAWR	38 13N	122 17W	56	6	6	6	6	6	6	6	6	6	6	6	6									
	NEEDLES	FAA	34 46N	114 37W	917	1	1	1	1	1	1	1	1	1	1	1	1			12						23179
	NEWARK	COOP	37 31N	122 02W	10																01					
	NEWPORT BCH	CG	33 36N	117 53W	10	3	3	3	3	3	3	3	3	3	3	3	3									
	NORTON	AFB	34 06N	117 15W	1113	1	1	1	1	1	1	1	1	1	1	1	1									23122
	OAKLAND	WSO	37 44N	122 12W	7	1	1	1	1	1	1	1	1	1	1	1	1			12			12			23230
	OCEANSIDE HB	CG	33 13N	117 24W	30	3	3	3	3	3	3	3	3	3	3	3										
	ONTARIO APT	FSS	34 03N	117 37W	949	1	1	1	1	1	1	1	1	1	1	1	1			12						03102
	OXNARD	LAWR	34 12N	119 12W	36	6	6	6	6	6	6	6	6	6	6	6	6									
	PALM SPRINGS	LAWR	33 50N	116 30W	421	6	6	6	6	6	6	6	6	5	6	6	6									93138
	PALMDALE	LAWR	34 38N	118 05W	2538	6	6	6	6	6	6	6	6	6	8	8	6									
	PALO ALTO	LAWR	37 28N	122 07W	3	6	6	6	5	6	6	6	8	6	6	6	6									23289
	PASO ROBLES	FAA	35 40N	120 38W	807	1	1	1	1	1	1	1	1	1	1	1	1			12						93209
	PEBBLY BEACH	SAWR	33 20N	118 19W	20	3	3	3	3	3	3	3	3	3		3										
	PIGEON POINT	CG	37 11N	122 24W	30	5	5	5	5	5	5	5	5	5	5	5	5									
	PILLAR PTAFS	CG	37 30N	122 30W	130	5	5	5	5		5	5	5	5	5	5	5									
	POINT BLUNT	CG	37 51N	122 25W	240	5	5	5	5	5	5	5	5													

TABLE A.1 WEATHER STATIONS IN CALIFORNIA OPERATING DURING 1976 (Continued).

YEAR	NAME	TYPE	LAT.	LONG.	ELEV.	J	F	M	A	M	J	J	A	S	O	N	D	SYNOPTIC FORM	MEIT SUMMARY	BAROGRAMS	THERMOGRAMS	TRIPLE REGISTER	WIND RECORDER	HUMIDITY RECORDER	RADAR LOGS	WBAN NUMBER
						HOURLY RECORDS BY MONTH 1 = 24 OBS PER DAY												NUMBER OF MONTHS IN YEAR WITH								
	POINT LOMA	CG	32 40N	117 29W	364	3	3	3	3	3	3	3														
	POINT PINOS	CG	36 38N	121 56W	20	5	5	5	5	5	5	5	5	5	5	5										
	PT ARENA	CG	38 57N	123 44W	63	5	5	5	5	5	5	5	5	5	5	5	5									23264
	PT ARGUELLO	CG	34 34N	120 40W	76	5	5	5	5	5	5	5	5	5	5	5	5									23265
	PT BONITA	CG	37 49N	122 32W	0								5	5	5	5										
	PT MUGU	NF	34 07N	119 07W	11	1	1	1	1	1	1	1	1	1	1	1	1			12	11		12			93111
	PT VICENTE	CG	33 45N	118 25W	79	5	5	5	5	5	5	5	5	5	5	5	5									
	RED BLUFF	WSO	40 09N	122 15W	344	1	1	1	1	1	1	1	1	1	1	1	1			12		12	12			24216
	REDDING	SAWR	40 30N	122 18W	495	6	6	6	6	6	6	6	6	6	8	6	6									24257
	RIO VISTA	CG	38 09N	121 42W	30	5	5	5	5	5	5	5	5	5	5	5	5									
	RIVERSIDE	LAWR	33 57N	117 27W	765	6	6	6	8	6	6	6	6	6	6	6	6									
	S E FARALLON	CG	37 42N	123 00W	46	3	3	3	3	3	3	3	3	3	3	3	3									23270
	SACRAMENTO	FAA	38 42N	121 36W	23	1	1	1	1	1	1	1	1	1	1	1	1									
	SACRAMENTO	WSO	38 31N	121 30W	43	1	1	1	1	1	1	1	1	1	1	1	1			12		12	12			23232
	SACRAMENTO	WBO	38 35N	121 30W	25																12				12	23271
	SALINAS	FAA	36 40N	121 36W	88	1	1	1	1	1	1	1	1	1	1	1	1			12						23233
	SAN CARLOS	LAWR	37 31N	122 15W	2	6	6	6	6	6	6	6	6	6	6	6	6									
	SAN CLEMENTE	NF	33 01N	118 35W	170	1	1	1	1	1	1	1	1	1	1	1	1			12	09		12			93117
	SAN DIEGO	WSMO	32 49N	117 08W	408													12		12						
	SAN DIEGO	NAS	32 42N	117 12W	48	1	1	1	1	1	1	1	1	1	1	1	1			12	12		12			93112
	SAN DIEGO BF	A	32 34N	116 59W	515	8	6	6	6	6	6	6	6	6	6	6	6									
	SAN DIEGO GF	A	32 49N	116 58W	375	1	1	1	1	1	1	1	1	1	1	6	6									
	SAN DIEGO LF	WSO	32 44N	117 10W	33	1	1	1	1	1	1	1	1	1	1	1	1			12		11	11			23188
	SAN DIEGO MF	A	32 49N	117 09W	417	6	6	5	6	6	6	6	6	6	6	6	8									03131
	SAN FRANCISC	WBO	37 47N	122 25W	52														12		12	10				23272
	SAN FRANCISC	WSO	37 37N	122 23W	90	1	1	1	1	1	1	1	1	1	1	1	1			12			12			23234
	SAN JOSE	LAWR	37 22N	121 55W	52	1	1	1	1	1	1	1	1	1	1	1	1									23293
	SAN JOSE TWR	LAWR	37 20N	121 49W	133	6	8	6	6	6	6	6	6	6	6	6	6									
	SAN LUIS OBI	SAWR	35 14N	120 39W	200	5	5	5		5	5	5	5	5	5	3	3									93206
	SAN MATEO PT	CG	33 23N	117 35W	65	5	5	5	5	5	5	5	5	5	5	5	5									
	SAN NICHOLAS	NF	33 15N	119 27W	568	5	5	5	6	6	6	6	6	6	6	6	6			12	12		12			93116
	SAN PEDRO	WBO	33 45N	118 16W	15				3	3	3	3	3	3	3	3	3									
	SANDBERG	WSO	34 45N	118 44W	4523	5	5	5	5	5	5	5	5	5	5	5	5			12	12					23187
	SANTA ANA	LAWR	33 40N	117 53W	53	6	6	6	6	6	8	8	6	6	6	6	6									93184
	SANTA ANA	MCAS	33 42N	117 50W	61	1	1	1	1	1	1	1	1	1	1	1	1			12	11		12			93114
	SANTA BARBAR	CG	34 24N	119 41W					5	5	5	5	5	5	5	5	5									
	SANTA BARBAR	FAA	34 26N	119 50W	13	1	1	1	1	1	1	1	1	1	1	1	1			12						23190
	SANTA CRUZ	CG	36 58N	122 00W	10	3	3	3	3	3	3	3	3	3	3	3	3									
	SANTA MARIA	SAWR	34 54N	120 27W	229	3	3	3	3	3	3	3	3	3	3	3	3						11			
	SANTA MARIA	WSO	34 54N	120 27W	270	8	8	6	6	6	8	6	6	6	6	8	6			12	12					23273
	SANTA MONICA	LAWR	34 01N	118 27W	175	6	6	8	8	6	6	6	6	6	6	6	6									
	SANTA ROSA	LAWR	38 31N	122 49W	148	6	6	6	6	8	8	8	6	8	8	8	6									23274
	SHELTER COVE	A	40 02N	124 04W	408	4	4	4	4	4	4	4	4	4	4	4	4			12	12					
	STOCKTON	WSO	37 54N	121 15W	37	1	1	1	1	1	1	1	1	1	1	1	1			12			12			23237
	SUSANVILLE	SA	40 23N	120 34W	4152	5	5	5	5	5	5	5	5	5	5	5	5			12						24258
	TAHOE VALLEY	LAWR	38 54N	120 00W	6329	6	6	6	6	8	6	6	6	8	8	6	6									
	THERMAL	FSS	33 38N	116 10W	-113	1	1	1	1	1	1	1	1	1	1	1	1			12						03104
	TORRANCE	LAWR	33 48N	118 20W	110	6	6	6	6	6	6	6	6	6	6	6	6									
	TRAVIS FIELD	AFB	38 16N	121 56W	59	1	1	1	1	1	1	1	1	1	1	1	1									23202
	TRUCKEE APT	A	39 19N	120 08W	5900	3	3	3	3	3	3	3	3	3	3	3	3									
	UKIAH	FAA	39 08N	123 12W	631	1	1	1	1	1	1	1	1	1	1	1	1			12						23275
	VAN NUYS	FAA	34 13N	118 29W	770	1	1	1	1	1	1	1	1	1	1	1	1									
	VANDENBERG	AFB	34 43N	120 34W	380	5	5	5	5	5	5	5	5	5	5	5	5									93214
	VENTURA MARI	CG	34 15N	119 16W	24			5	5	5	5	5	5	5	5	5	5									
	VISALIA	SAWR	36 20N	119 24W	288	5	5	5	5	5	5	5	5	5	5	5	5									93144
	ZUMA BEACH	CG	34 01N	118 49W	20									3	3	3	3									

Code	Type of Station
Weather Bureau	
A	Aviation Reports & Coop-A Stations
AC	Cooperative Aviation Reports
S	Synoptic Reports
SA	Synoptic and Aviation Reports
SAC	Cooperative Synoptic and Aviation Reports
SC	Cooperative Synoptic Reports
WBAS	Weather Bureau Airport Station
WBFO	Weather Bureau Forecast Office
WBMO	Weather Bureau Meteorological Observatory
WBO	Weather Bureau Office
WBUA	Weather Bureau Upper Air Unit
WSFO	Weather Service Forecast Office
WSMO	Weather Service Meteorological Observatory
WSO	Weather Service Office
Others	
AMOS	Automatic Weather Station
CAA	Civil Aeronautics Adm. Facility
CG	Coast Guard
COOP	Cooperative
FAA	Federal Aviation Agency
FSS	Flight Service Station (FAA)
LAWR	Limited Airport Weather Reporting Station (Tower)
MARS	Marine Reporting Station
SAWR	Supplementary Airways Weather Reporting Station
SPL	Special Purpose Office (Fire weather, temporary observing sites)

Code	Type of Station
Military	
AAB	Army Air Base
AAF	Army Air Field
AAFB	Auxiliary Air Force Base
AB	Air Base (Air Force)
AF	Air Force
AFB	Air Force Base
AFS	Air Force Station
ANG	Air National Guard
ASC	Army
MCAF	Marine Corps Air Facility
MCAS	Marine Corps Air Station
NAAF	Naval Auxiliary Air Facility
NAAS	Naval Auxiliary Air Station
NAF	Naval Air Facility
NAS	Naval Air Station
NF	Naval Facility
NS	Naval Station

APPENDIX B

Summary of Stations in California With Computerized Weather Data

TABLE B.1 WEATHER STATIONS IN CALIFORNIA WITH COMPUTERIZED DATA.

WBAN STATION NO.	SERVICE	STATION		PERIOD	NO. REEL
23239	N	Alameda		03/45-12/74	4
24283	F	Arcata		12/49-12/75	3
24245	N	Arcata		04/45-04/46	1
23155	W	Bakersfield/Meadows Fld.		01/48-12/75	3
93216	A	Beale		07/59-12/70	2
23156	W	Beaumont	*	01/48-08/53	1
23157	W	Bishop	*	01/48-12/75	3
23225	W	Blue Canyon	*	01/48-12/75	3
23158	F	Blythe/Riverside Cnty.		01/48-12/54	1
23152	F	Burbank		01/48-12/68	2
03154	N	Camp Pendleton	*	07/66-12/74	1
93104	N	China Lake/Inyokern	*	04/45-12/74	3
23196	N	Chula Vista/Brown Fld.	*	04/45-05/46; 07/54-04/61	2
23254	W	Concord/Buchanan Fld.	*	01/69-12/69	1
24286	F	Crescent City/McNamara		10/49-12/54	1
23240	N	Crows Landing		03/45-05/46	1
03147	A	Cuddeback	*	07/63-12/70	1
23161	F	Daggett/San Bernadino		11/48-12/75	3
23266	F	Donner Summit	*	11/48-01/52	1
23114	A	Edwards		01/49-12/70	3
23199	N	El Centro	*	02/45-10/60	2
93101	N	El Toro		03/45-12/74	3
24213	W	Eureka/WBO		01/48-01/49	2
23202	A	Fairfield/Travis		01/49-12/70	3
03122	A	Fort McArthur/Torrance		05/53-03/54	1
93217	A	Ft. Ord/Fritzsche	*	04/60-12/70	1
93193	W	Fresno/Air Terminal		09/49-12/75	3
23167	W	Fresno/Chandler		01/48-08/49	1
93124	N	Goleta/Santa Barbara	*	04/45-02/46	1
93103	N	Holtville		03/45-02/46	1
93115	N	Imperial Beach/Ream Fld.	* *	04/45-08/48; 01/52-12/74	4
23172	W	Indio/Coachella		11/48-05/50	1
93218	N	Jolon		07/64-07/71	1
23110	N	Lemoore		07/61-12/74	1
23242	N	Livermore		02/45-08/46	1
23129	W	Long Beach/Daugherty		01/49-12/75	3
03157	N	Long Beach	*	07/72-12/72	1
93106	N	Los Alamitos	*	04/45-07/71	3
23174	W	Los Angeles/Int.		01/47-12/75	3

TABLE B.1 WEATHER STATIONS IN CALIFORNIA WITH COMPUTERIZED DATA (Continued).

WBAN STATION NO.	SERVICE	STATION		PERIOD	NO. REELS
23203	A	Merced/Castle		01/49-12/70	3
93107	N	Miramar	*	07/47-12/74	4
03129	N	Mojave	*	01/55-09/58	1
93108	N	Mojave	*	04/45-12/46	1
24259	F	Montague/Siskiyou Cnty. (unedited 1/55-12/65)		01/50-12/65	2
24214	W	Montague	*	01/48-12/49	1
23245	N	Monterey	*	03/45-12/70	5
23178	W	Mount Laguna		11/48-02/50	1
24215	W	Mount Shasta/WBO	*	04/48-12/75	3
23179	F	Needles/Mun.		11/48-12/64	2
23180	F	Newhall		09/48-07/49	1
23230	W	Oakland/Metro. Int.		01/48-12/75	3
93211	N	Oakland	*	06/49-07/51;	
			*	03/54-10/54	1
23181	F	Oceanside		11/48-01/52	1
03102	F	Ontario/Int.		01/68-12/72	1
93180	W	Ontario (unedited 10/49-9/55)	*	10/49-12/53;	
			*	01/55-09/55	1
23136	A	Oxnard/Ventura		12/52-12/69	3
93110	N	Oxnard	*	08/45-10/45;	
			*	01/61-12/64	2
23182	F	Palmdale		01/48-12/54;	
				01/61-12/64	2
93209	F	Paso Robles/Cnty.		03/52-12/64	2
23231	W	Paso Robles/Cnty.		01/48-03/52	2
93215	W	Pt. Arguello		07/59-03/65	1
93111	N	Pt. Mugu		03/46-12/74	4
24216	W	Red Bluff/Mun.		01/48-12/75	3
23119	A	Riverside/March		01/49-12/70	3
23232	F	Sacramento/Executive		07/47-12/75	3
23206	A	Sacramento/Mather		01/49-12/70	3
23208	A	Sacramento/McClellan		01/49-12/70	3
23233	F	Salinas/Mun.		11/48-12/64	2
23122	A	San Bernardino/Norton		01/49-12/70	3
93117	N	San Clemente	*	04/60-12/74	2
23187	W	Sandberg	*	01/48-12/75	3
23188	W	San Diego/Int.		01/48-12/75	3
93112	N	San Diego/N. Island		04/45-12/74	3
23272	W	San Francisco/WBO	*	01/45-12/47	1
23234	W	San Francisco/Int.		01/48-12/75	3

TABLE B.1 WEATHER STATIONS IN CALIFORNIA WITH COMPUTERIZED DATA (Continued).

WBAN STATION NO.	SERVICE	STATION		PERIOD	NO. REELS
23293	W	San Jose/Mun.	*	01/51-12/52; 01/68-12/72	2
93116	N	San Nicolas	*	04/45-12/74	4
93113	N	San Pedro/Terminal Is.		03/45-05/47	1
23211	A	San Rafael/Hamilton		01/49-12/70	3
93114	N	Santa Ana	* * *	03/45-07/47; 10/51-08/52; 03/53-12/74	4
93184	W	Santa Ana/Orange Cnty.	*	01/68-12/72	1
23190	F	Santa Barbara/Mun.		01/48-12/54; 01/57-12/64	2
23191	W	Santa Catalina/Catalina	*	01/48-06/53; 05/67-03/68	2
23236	W	Santa Maria		01/48-10/54	1
23273	W	Santa Maria/Public	*	10/54-12/75	2
23246	N	Santa Rose	# *	03/45-04/47	1
23192	F	Silver Lake		11/48-07/50	1
23237	W	Stockton/Metro.		11/48-12/54; 03/63-12/75	2
23244	N	Sunnyvale/Moffett Fld.		03/45-12/74	3
03104	F	Thermal		05/50-01/54	1
23275	F	Ukiah/Mun.		09/49-12/64	2
93214	A	Vandenberg/Cooke	*	07/51-12/74	3
93219	A	Vandenberg/Boat House		08/66-03/69	1
23130	A	Van Nuys		01/49-05/50; 10/61-08/62	1
23131	A	Victorville/George		09/50-12/70	3
23238	F	Williams		11/48-12/52	1

A = Air Force

N = Navy

W = National Weather Service

F = Federal Aviation Administration

* = Less than 24 hours per day for part of record

= Part of period missing

APPENDIX C

Cumulative Frequency Distributions of Visibility for the 67 Study Locations

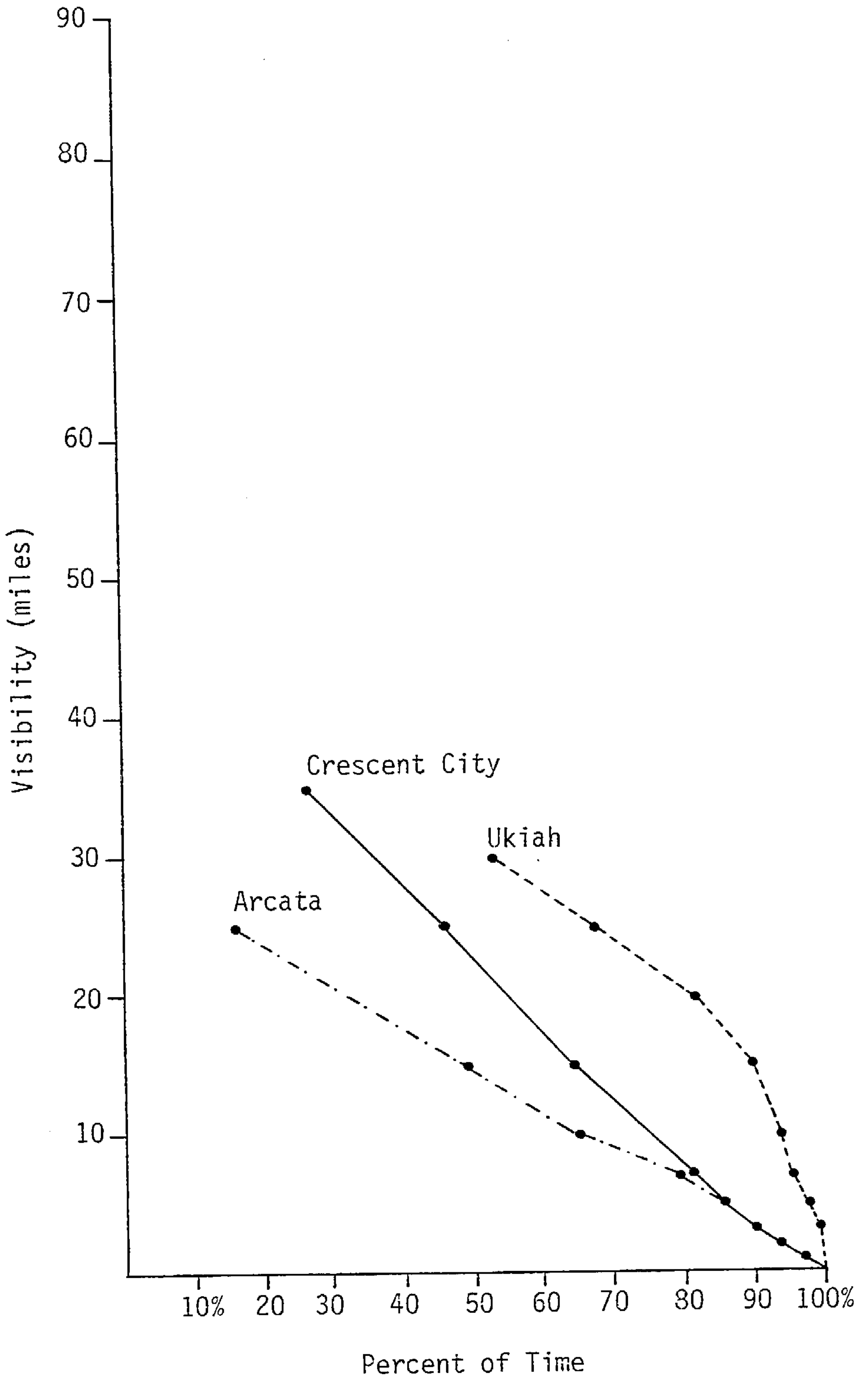

Figure C.1 Visibility frequency distributions for the North Coast Air Basin.

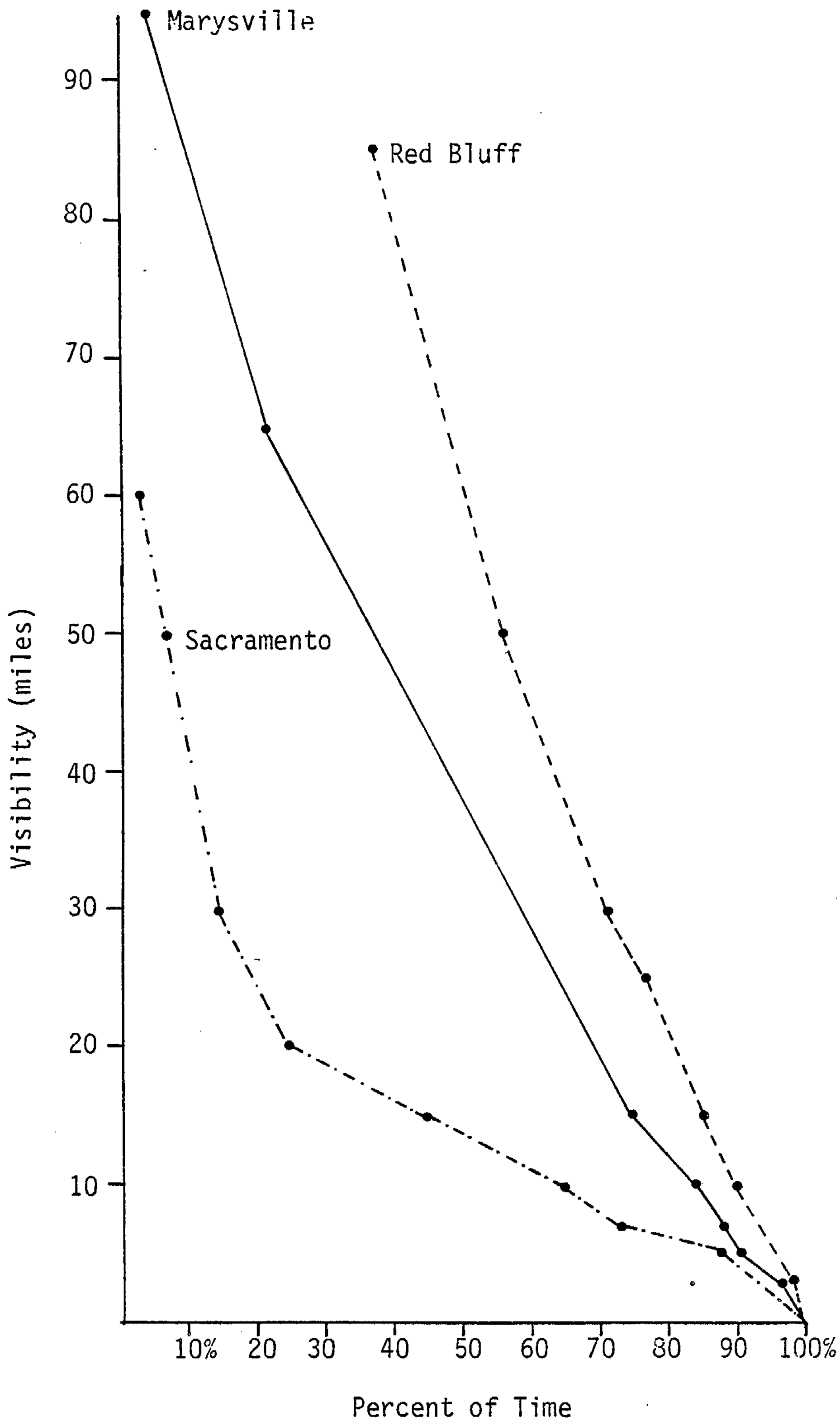

Figure C.2 Visibility frequency distributions for the Sacramento Valley Air Basin.

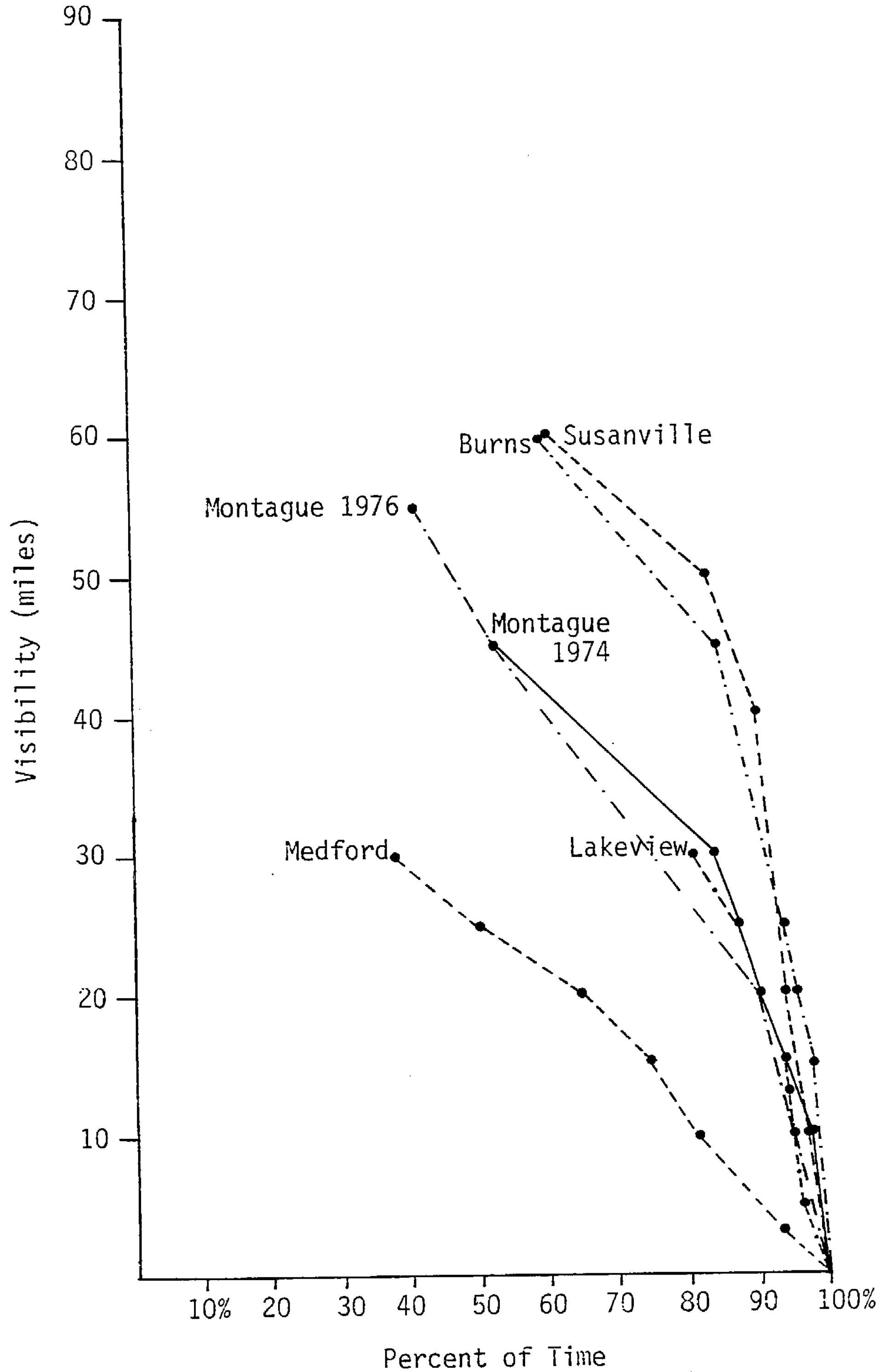

Figure C-3 Visibility frequency distributions for the Northeast Plateau Air Basin and southern Oregon.

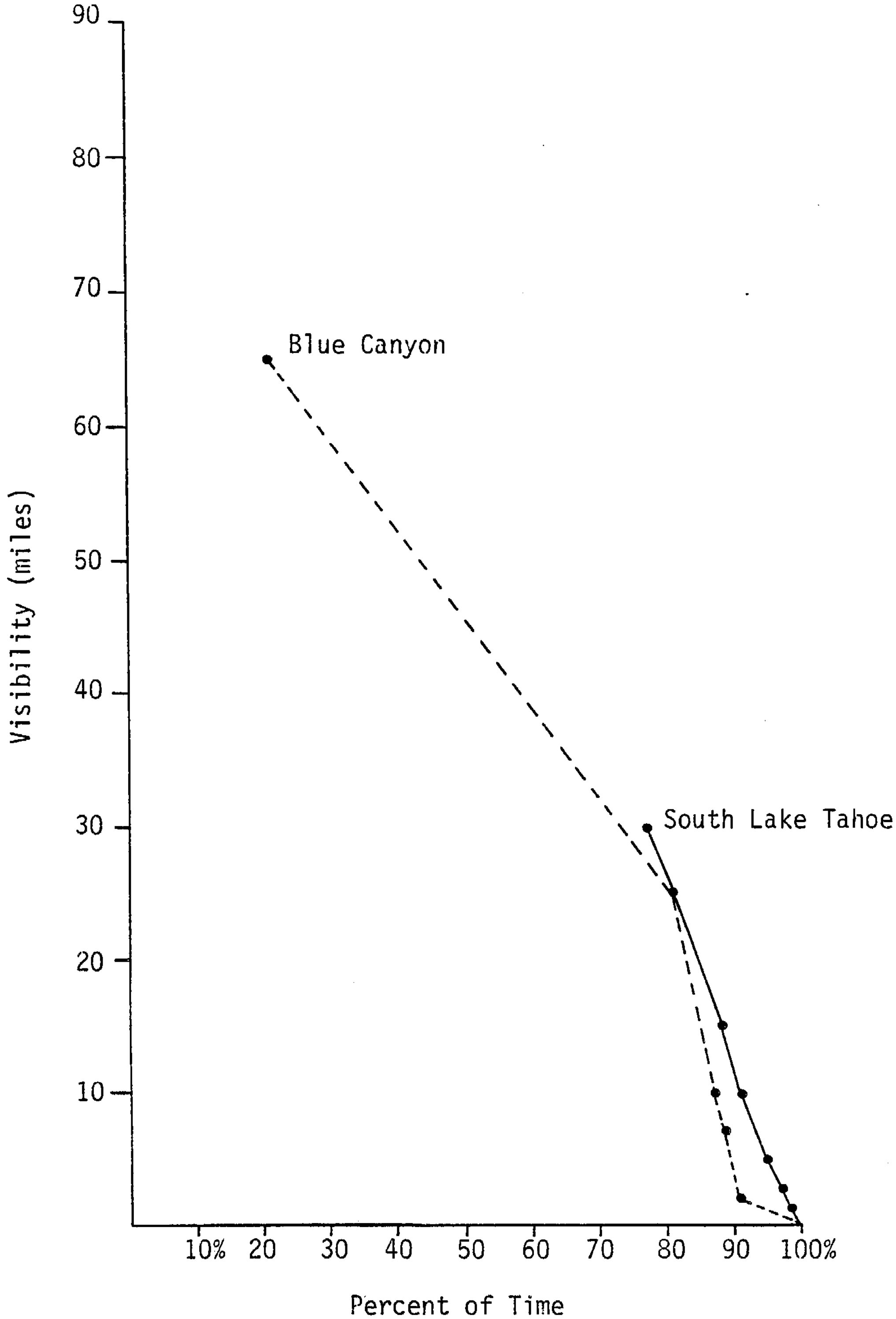

Figure C.4 Visibility frequency distributions for the Mountain Counties and Lake Tahoe Air Basins.

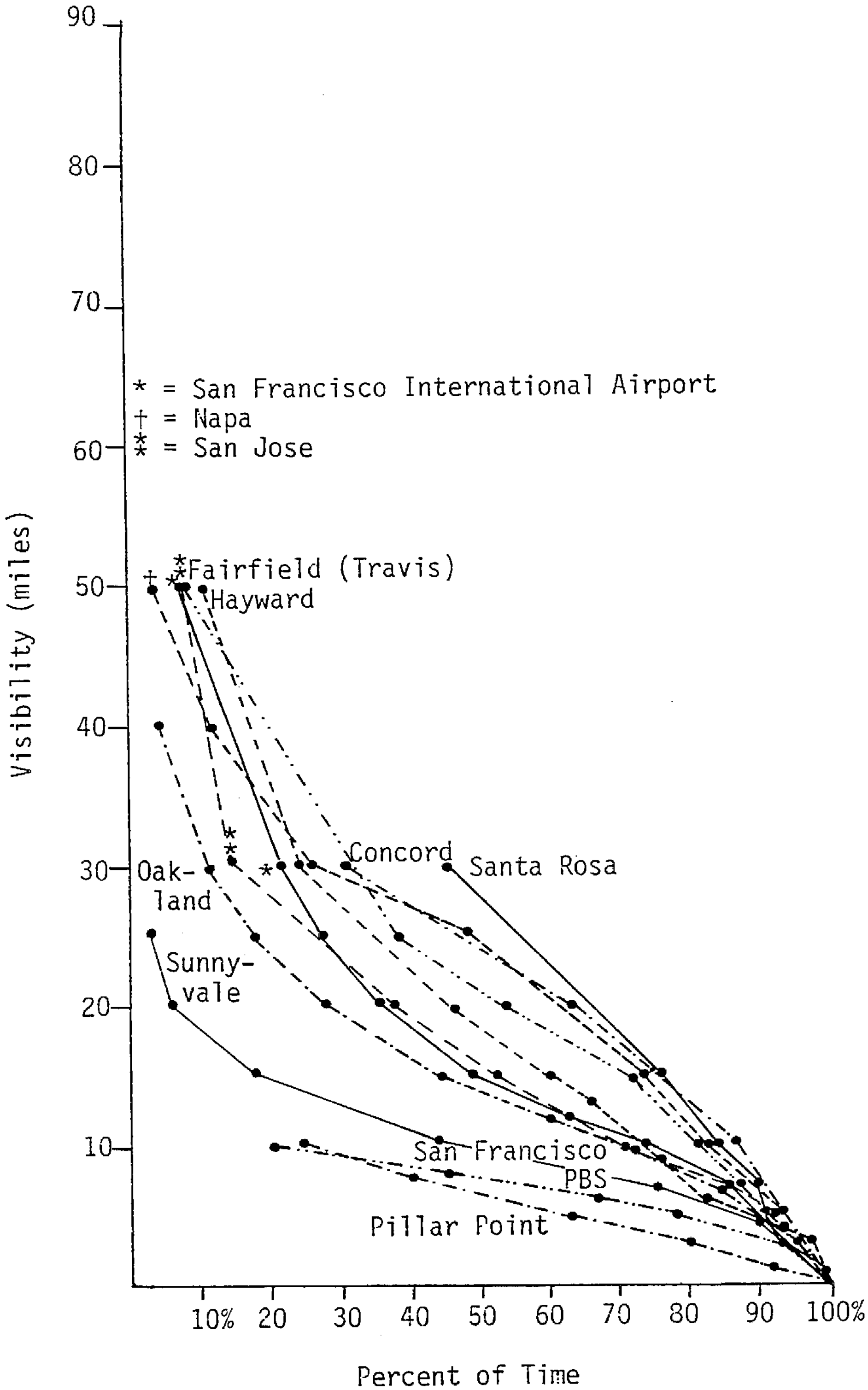

Figure C.5 Visibility frequency distributions for the San Francisco Bay Area Air Basin.

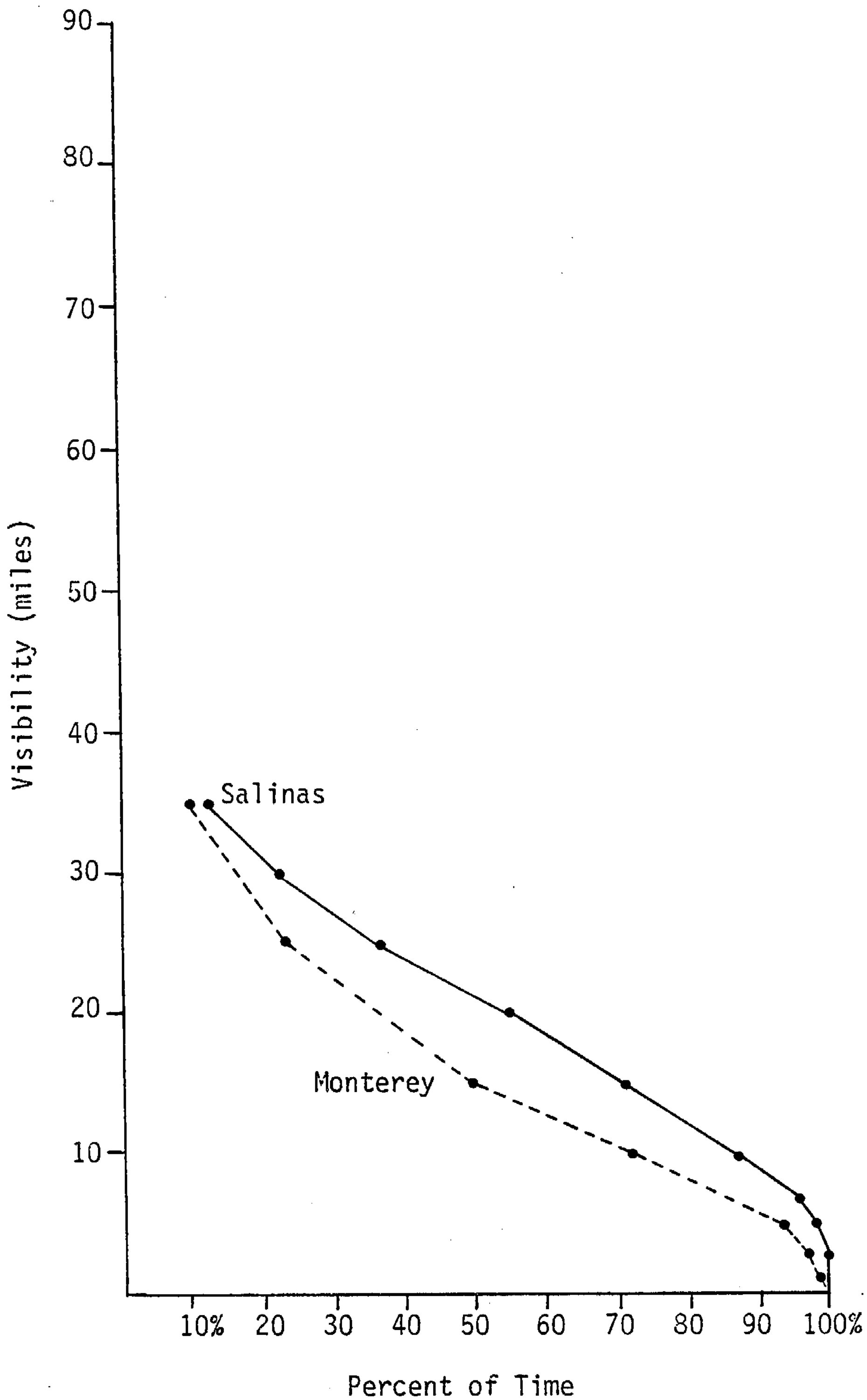

Figure C.6 Visibility frequency distributions for the North Central Coast Air Basin.

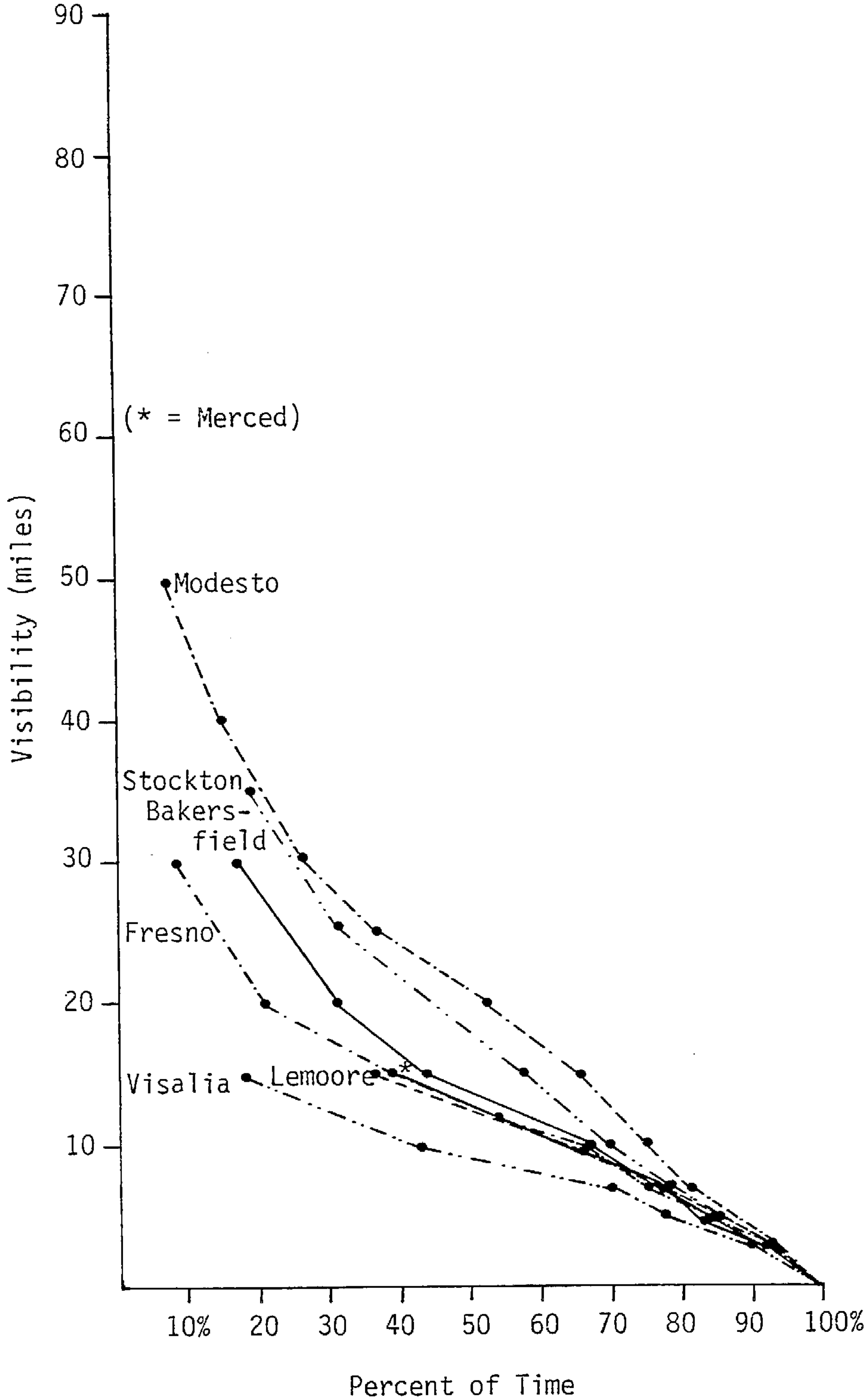

Figure C.7 Visibility frequency distributions for the San Joaquin Valley Air Basin.

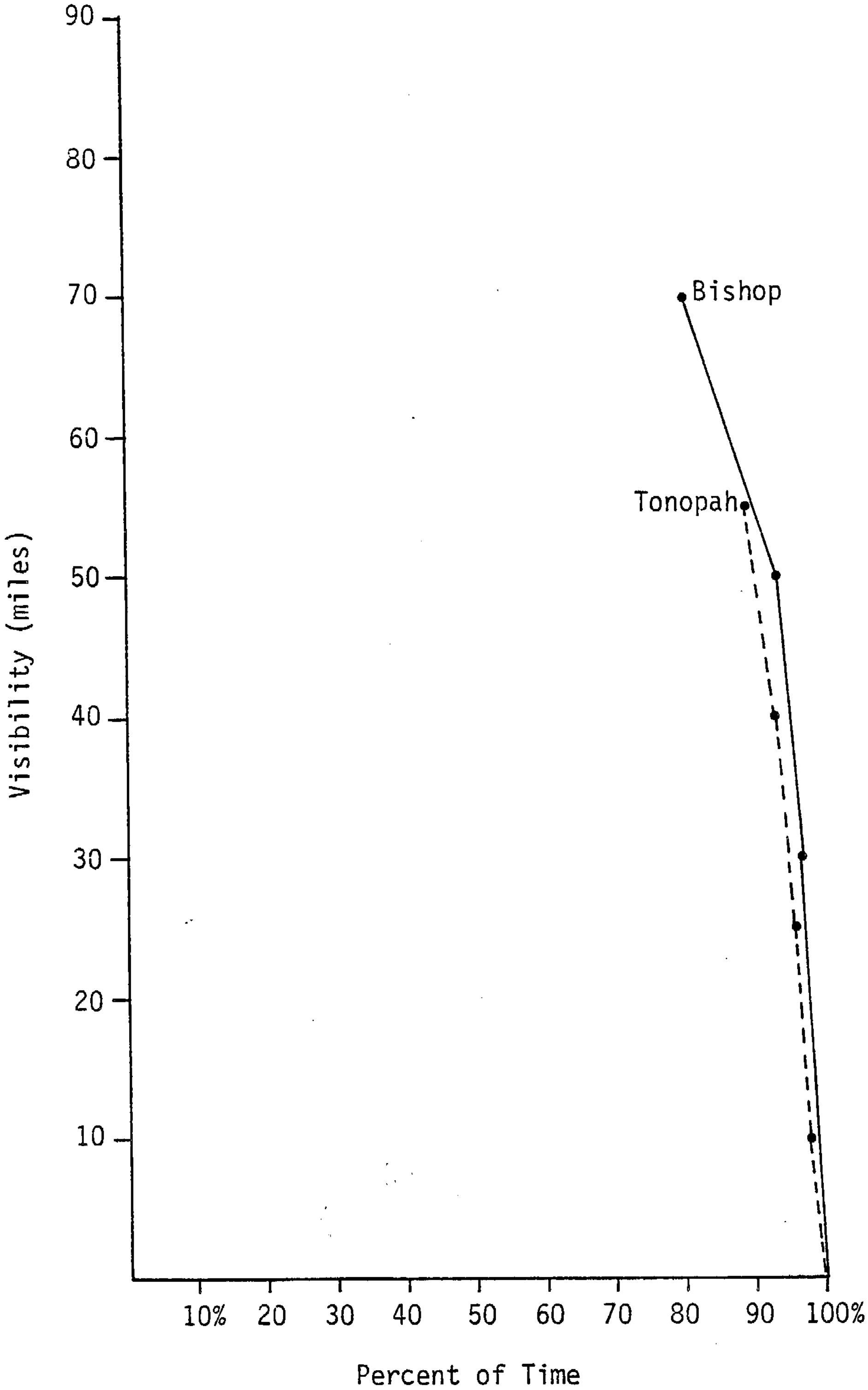

Figure C.8 Visibility frequency distributions for the Great Basin Valleys and western Nevada.

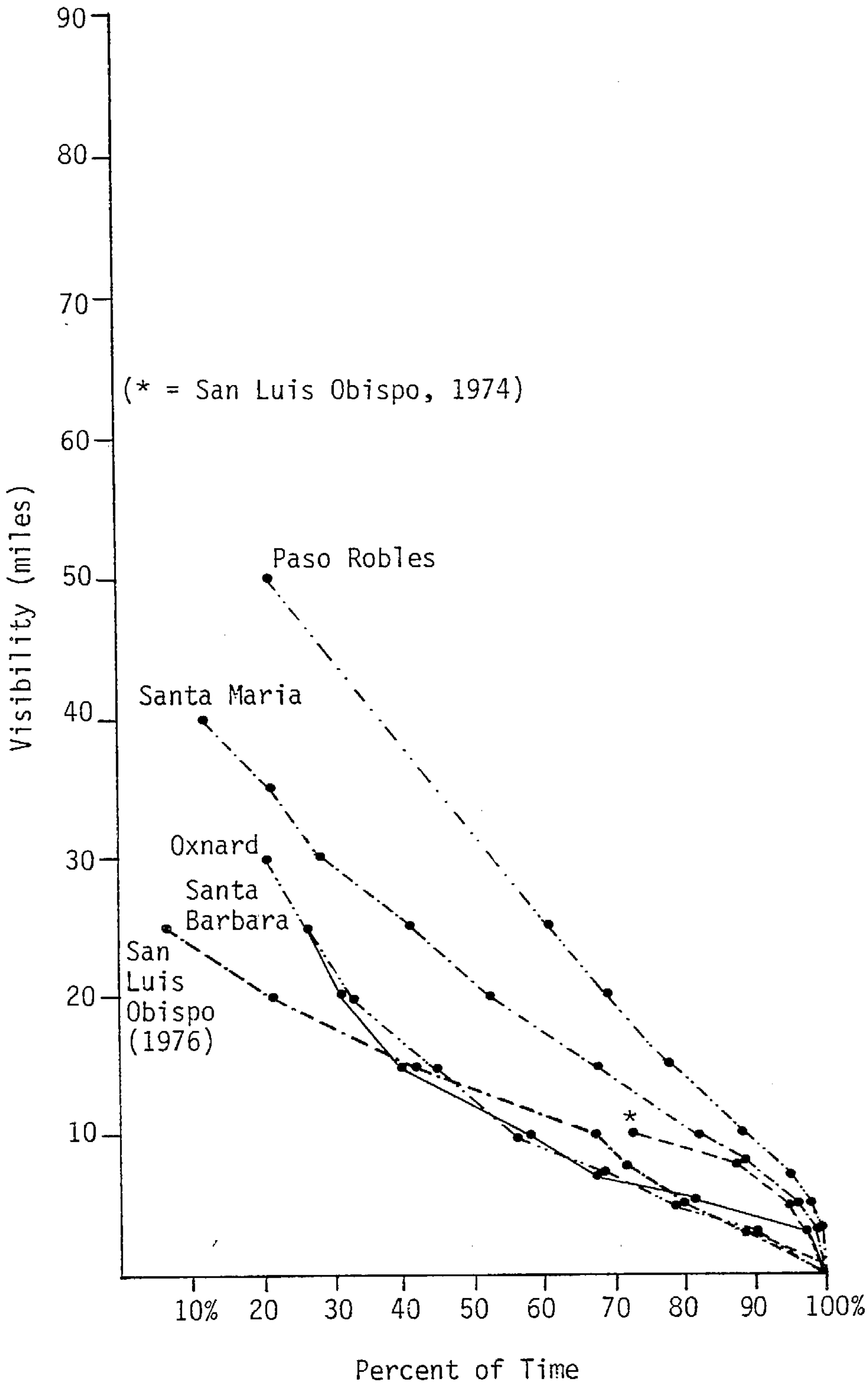

Figure C.9 Visibility frequency distributions for the South Central Coast Air Basin.

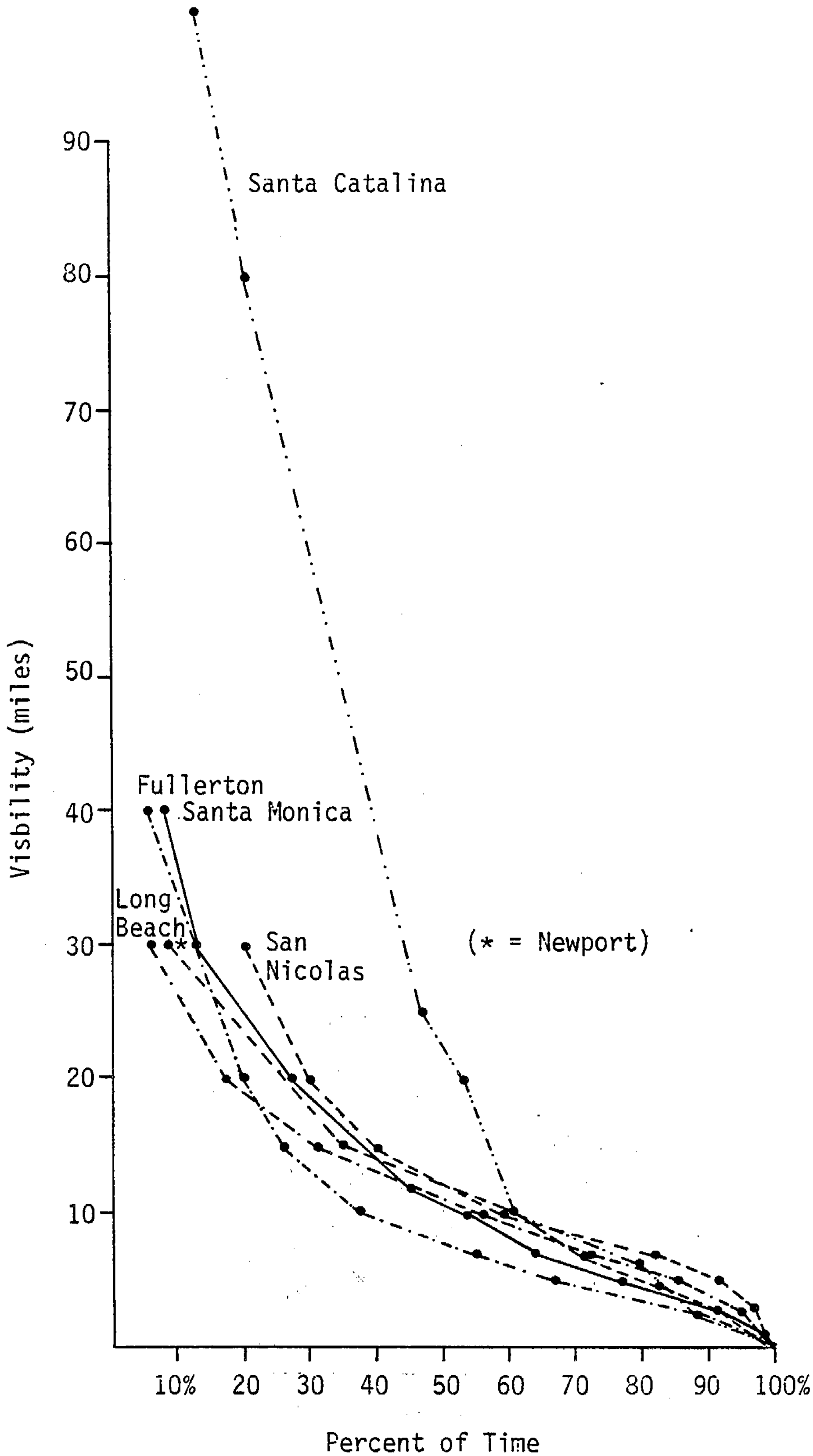

Figure C.10 Visibility frequency distributions for the coastal part of the South Coast Air Basin.

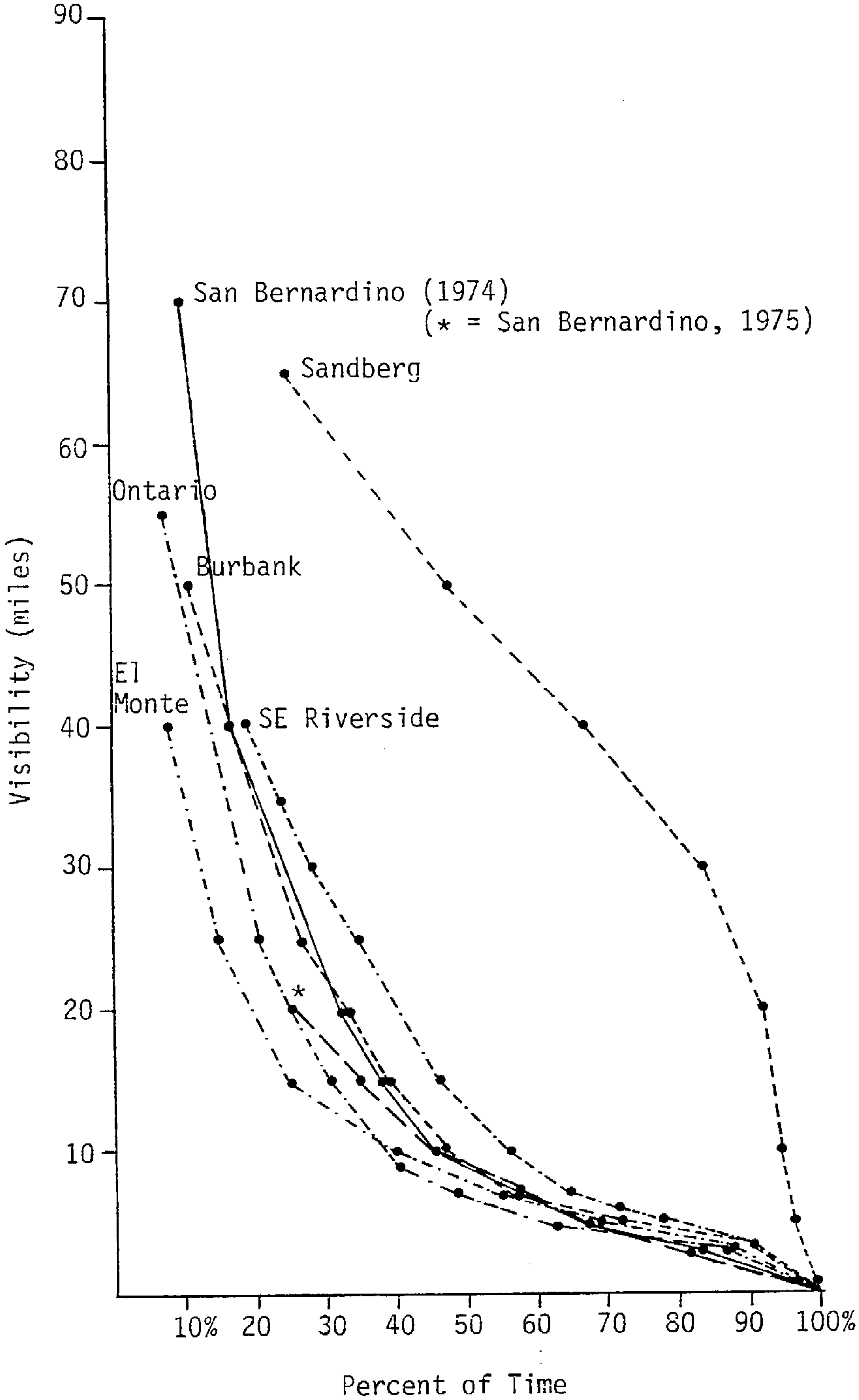

Figure C.11 Visibility frequency distributions for the Inland Part of South Coast Air Basin.

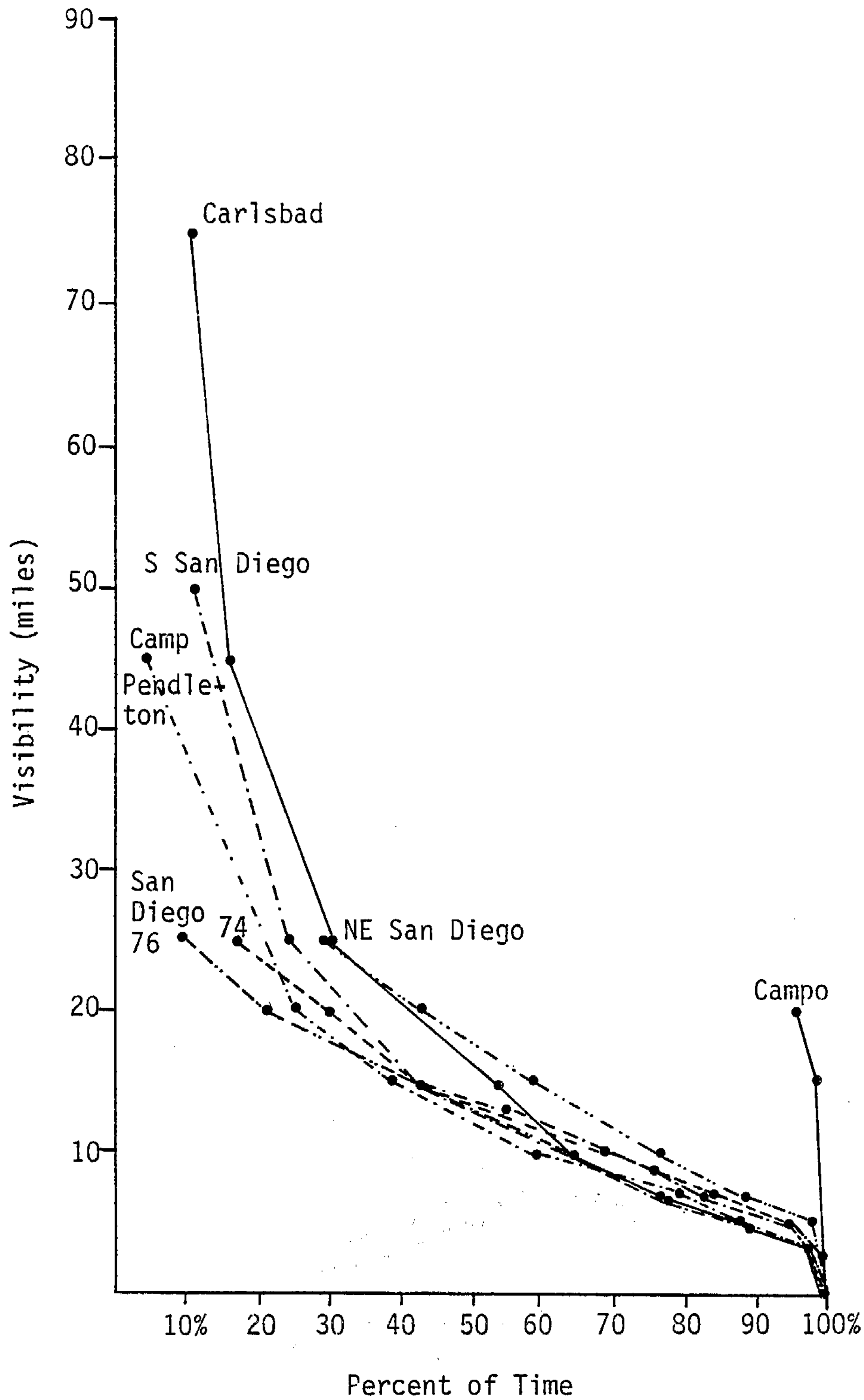

Figure C.12 Visibility frequency distributions for the San Diego Air Basin.

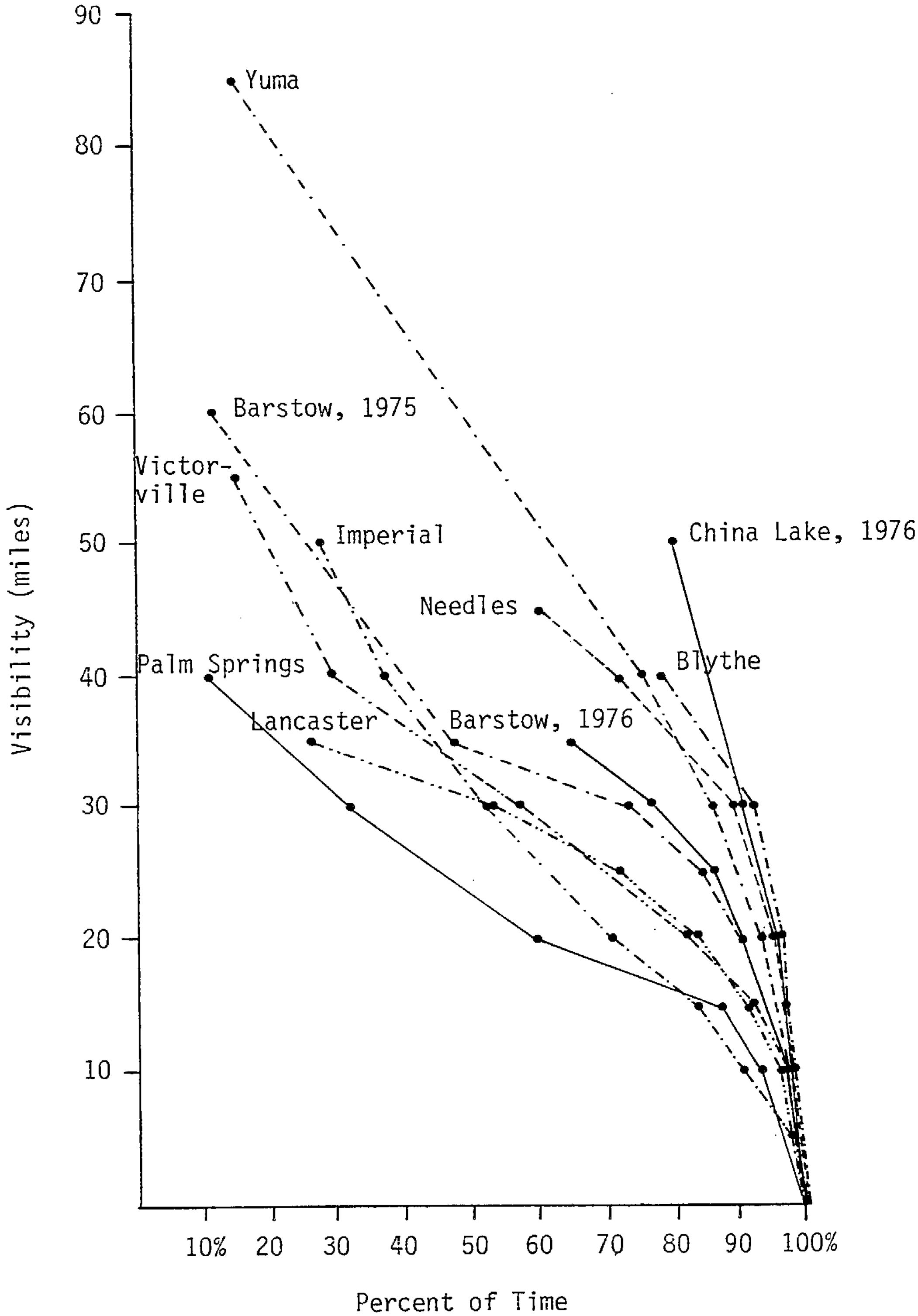

Figure C.13 Visibility frequency distributions for the Southeast Desert Air Basin and eastern Arizona.

APPENDIX D

VISIBILITY/AEROSOL REGRESSION STUDIES FOR THE DATA SETS EXCLUDING DAYS WITH PRECIPITATION OR SEVERE FOG

TABLE D.1 INTERCORRELATIONS AMONG THE INDEPENDENT VARIABLES IN THE VISIBILITY/AEROSOL REGRESSION STUDIES.

DATA: Excluding Days with Precipitation or Severe Fog

LOCATION	S vs N	S vs T	S vs RH	N vs T	N vs RH	T vs RH
	CORRELATION COEFFICIENTS					
SOUTH COAST AIR BASIN						
Burbank	-.07*	.16*	.32	.42	-.13*	-.13*
Long Beach	-.09*	.33	.26	.34	-.12*	-.30
Ontario	.21*	.57	.01*	.41	-.26	-.20*
San Bernardino	.75	.66	.23*	.70	.17*	-.11*
SAN FRANCISCO BAY AREA AIR BASIN						
Oakland	.36	.50	.10*	.42	-.11*	-.32
San Jose	.19	.03*	-.24	.61	.10*	.18
OTHER COASTAL LOCATIONS						
Paso Robles	.47	.35	.21	.56	.37	-.10*
San Diego	.01*	.16	.41	.17	-.12*	-.45
SAN JOAQUIN VALLEY AIR BASIN						
Bakersfield	.63	.08*	.58	.35	.37	-.31
Fresno	.32	.10*	.12*	.25	.11*	-.19*
SACRAMENTO VALLEY AIR BASIN						
Red Bluff	.41	.43	-.01*	.32	.37	-.32
Sacramento	.41	.17	.01*	.24	.19	-.32
Average Over Sites	.30	.30	.17	.40	.08	-.21

*Not statistically significant at 95% confidence level.

TABLE D.2 SUMMARY STATISTICS FOR LOCATIONS INCLUDED IN VISIBILITY/AEROSOL REGRESSION STUDIES.

DATA: Excluding Days with Precipitation or Severe Fog

LOCATION	NUMBER OF DATA POINTS	AVERAGE VALUES FOR KEY PARAMETERS				
		$B = 24.3/V$ $(10^4\ m)^{-1}$	$S = 1.3SO_4^=$ $(\mu g/m^3)$	$N = 1.3NO_3^-$ $(\mu g/m^3)$	$T = TSP - S - T$ $(\mu g/m^3)$	RH (%)
SOUTH COAST AIR BASIN						
Burbank	128	3.83	15.5	10.8	109.5	50.8
Long Beach	162	4.14	16.1	8.9	91.2	55.9
Ontario	67	5.96	12.3	12.4	101.2	48.9
San Bernardino	69	3.89	15.1	15.3	93.2	46.9
SAN FRANCISCO BAY AREA AIR BASIN						
Oakland	186	2.28	9.1	4.9	66.0	71.1
San Jose	148	2.47	3.2	8.3	59.3	71.7
OTHER COASTAL LOCATIONS						
Paso Robles	95	1.77	7.8	7.5	66.8	52.2
San Diego	175	2.99	11.0	6.1	56.5	62.3
SAN JOAQUIN VALLEY AIR BASIN						
Bakersfield	124	6.14	16.1	22.7	127.5	50.2
Fresno	104	3.30	7.0	10.3	113.6	51.5
SACRAMENTO VALLEY AIR BASIN						
Red Bluff	73	0.90	3.9	6.1	64.1	42.5
Sacramento	159	3.01	6.6	6.1	63.8	55.8

TABLE D.3 CORRELATION BETWEEN EXTINCTION AND THE INDEPENDENT VARIABLES.

DATA: Excluding Days with Precipitation or Severe Fog

LOCATION	CORRELATION COEFFICIENTS B vs S	B vs N	B vs T	B vs RH
SOUTH COAST AIR BASIN				
Burbank	.64	-.19*	.17*	.47
Long Beach	.67	-.03*	.38	.39
Ontario	.52	-.05*	.37	.45
San Bernardino	.75	.64	.56	.51
SAN FRANCISCO BAY AREA AIR BASIN				
Oakland	.76	.35	.53	.30
San Jose	-.04*	.43	.37	.48
OTHER COASTAL LOCATIONS				
Paso Robles	.46	.74	.34	.58
San Diego	.86	-.04*	.10*	.41
SAN JOAQUIN VALLEY AIR BASIN				
Bakersfield	.60	.35	-.11*	.53
Fresno	.28	.16*	-.01*	.59
SACRAMENTO VALLEY AIR BASIN				
Red Bluff	.22*	.76	.14*	.50
Sacramento	.32	.35	.03*	.56
Average Over Sites	.50	.29	.24	.48

*Not positive and/or not statistically significant at 95% confidence level.

TABLE D.4 SUMMARY OF LINEAR EXTINCTION/AEROSOL REGRESSIONS.

DATA: Excluding Days with Precipitation or Severe Fog

REGRESSION EQUATION: $B = a' + b_1S + b_2N + b_3T + b_4(RH - \overline{RH})$

LOCATION	TOTAL CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS a'	b_1	b_2	b_3	b_4
SOUTH COAST AIR BASIN						
Burbank	.71	-.67	.21	NS	.012	.105
Long Beach	.76	-3.30	.24	NS	.040	.139
Ontario	.72	-.44	.26	NS	.031	.164
San Bernardino	.85	.13	.14	NS	.019	.087
SAN FRANCISCO BAY AREA AIR BASIN						
Oakland	.82	.09	.12	NS	.016	.048
San Jose	.62	1.59	NS	.11	NS	.074
OTHER COASTAL LOCATIONS						
Paso Robles	.82	-.08	.09	.16	NS	.041
San Diego	.86	-.69	.34	NS	NS	NS
SAN JOAQUIN VALLEY AIR BASIN						
Bakersfield	.64	-3.74	.61	NS	NS	.204
Fresno	.62	2.07	.18	NS	NS	.141
SACRAMENTO VALLEY AIR BASIN						
Red Bluff	.80	-.03	NS	.15	NS	.018
Sacramento	.66	-.35	.31	NS	.020	.154

NS = Not significantly greater than zero at the 95% confidence level.

TABLE D.5 SUMMARY OF NONLINEAR RH EXTINCTION/AEROSOL REGRESSIONS.

DATA: Excluding Days with Precipitation or Severe Fog

REGRESSION EQUATION: $B = a + b_1 \frac{S}{1 - \frac{RH}{100}} + b_2 \frac{N}{1 - \frac{RH}{100}} + b_3 \frac{T}{1 - \frac{RH}{100}}$

LOCATION	TOTAL CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS a'	b_1	b_2	b_3
SOUTH COAST AIR BASIN					
Burbank	.71	-.23	.067	NS	.006
Long Beach	.90	-2.67	.068	NS	.017
Ontario	.87	-.88	.119	NS	.015
San Bernardino	.90	-.44	.044	.032	.009
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	.83	.37	.023	.007	.004
San Jose	.73	.97	NS	.015	.003
OTHER COASTAL LOCATIONS					
Paso Robles	.89	-.02	.026	.041	.003
San Diego	.90	.37	.074	NS	NS
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	.95	-1.94	.054	.062	NS
Fresno	.91	.30	.081	.039	NS
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	.89	-.11	NS	.040	.004
Sacramento	.88	-1.11	.084	NS	.013

NS = Not significantly greater than zero at the 95% confidence level.

TABLE D.6 EXTINCTION BUDGETS BASED ON THE LINEAR REGRESSION MODEL.

DATA: Eliminating Days with Precipitation or Severe Fog

LOCATION	CONTRIBUTIONS TO TOTAL EXTINCTION Blue-sky Scatter	Sulfates	Nitrates	Remainder of TSP	Unaccounted for
SOUTH COAST AIR BASIN					
Burbank	3%	84%	0%	34%	-21%
Long Beach	3%	93%	0%	87%	-83%
Ontario	2%	54%	0%	53%	- 9%
San Bernardino	3%	52%	0%	45%	0%
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	5%	49%	0%	47%	- 1%
San Jose	5%	0%	36%	0%	59%
OTHER COASTAL LOCATIONS					
Paso Robles	7%	38%	66%	0%	-11%
San Diego	4%	123%	0%	0%	-27%
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	2%	161%	0%	0%	-63%
Fresno	4%	37%	0%	0%	59%
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	13%	0%	103%	0%	-16%
Sacramento	4%	68%	0%	43%	-15%
Average for All Sites	5%	63%	17%	26%	-11%

Note: The zero contributions for certain aerosol species imply only that a statistically significant relationship was not observed in the multiple regressions and do not necessarily mean that the actual contributions are zero (see discussion on page 135).

TABLE D.7 EXTINCTION BUDGETS BASED ON THE NONLINEAR RH REGRESSION MODEL.

DATA: Eliminating Days with Precipitation or Severe Fog

LOCATION	CONTRIBUTIONS TO TOTAL EXTINCTION				
	Blue-sky Scatter	Sulfates	Nitrates	Remainder of TSP	Unaccounted for
SOUTH COAST AIR BASIN					
Burbank	3%	68%	0%	38%	- 9%
Long Beach	3%	72%	0%	92%	-67%
Ontario	2%	58%	0%	57%	-17%
San Bernardino	3%	38%	28%	45%	-14%
SAN FRANCISCO BAY AREA AIR BASIN					
Oakland	5%	36%	6%	42%	11%
San Jose	5%	0%	25%	36%	34%
OTHER COASTAL LOCATIONS					
Paso Robles	7%	28%	47%	26%	- 8%
San Diego	4%	88%	0%	0%	8%
SAN JOAQUIN VALLEY AIR BASIN					
Bakersfield	2%	53%	78%	0%	-33%
Fresno	4%	56%	35%	0%	5%
SACRAMENTO VALLEY AIR BASIN					
Red Bluff	13%	0%	62%	51%	-26%
Sacramento	4%	60%	0%	77%	-41%
Average for All Sites	5%	46%	23%	39%	-13%

Note: The zero contributions for certain aerosol species imply only that a statistically significant relationship was not observed in the multiple regressions and do not necessarily mean that the actual contributions are zero (see discussion on page 135).

APPENDIX E

STATISTICAL TESTS FOR DETERMINING THE SIGNIFICANCE OF RELOCATIONS IN VISIBILITY OBSERVATION SITES

This appendix describes the two statistical tests for examining the effect of observation site relocations on reported visibilities. Both tests are based on quarterly median visibilities, and both use approximately four years of data (two before and two after the time of the relocation). The analysis is restricted to only two years on either side of the relocation in order to help minimize the possibility that long-term trends will be confused with the jump in visibility caused by the relocation. Quarterly values are used because they are readily computed by our data processing programs and because yearly values would yield too few data points.

Test 1. Net Jump in Quarterly Medians

The first test is best illustrated by example. Assume a relocation occurred during the 3rd quarter of 1965. Then the data points used are as follows:

1963	4th quarter median	x_1
	1st quarter median	x_2
1964	2nd quarter median	x_3
	3rd quarter median	x_4
	4th quarter median	x_5
	1st quarter median	x_6
1965	2nd quarter median	x_7
	3rd quarter median	relocation
	4th quarter median	y_1
	1st quarter median	y_2
1966	2nd quarter median	y_3

	3rd quarter median - - - - - - - - - - - - - - - - - -	y_4
	4th quarter median - - - - - - - - - - - - - - - - - -	y_5
	1st quarter median - - - - - - - - - - - - - - - - - -	y_6
1967	2nd quarter median - - - - - - - - - - - - - - - - - -	y_7

Seven quarterly changes in visibility are computed as $z_i = y_i - x_i$, $i = 1, \ldots, 7$. The estimated net jump in visibility is simply the average value ($\overline{z}_i$), and the t-statistic for the jump is $\overline{z}_i/\sigma_z\sqrt{7})$, where σ_z is the standard deviation of the z_i.

Test 2. Multivariate Regression Test on Seasonally Adjusted Quarterly Medians

The first test has the advantage that it is simple and automatically discounts for seasonal trends in the data. The major disadvantage is that it could easily confuse a gradual trend in the data with a jump produced by the relocation. To account for this latter possibility, we also conducted a simple multiple regression test.

The data for the regression test consist of two years of seasonally adjusted* quarterly medians before the relocation ($z_{-8}, z_{-7}, \ldots, z_{-1}$) and two years of seasonally adjusted quarterly medians after the relocation ($z_1, z_2, \ldots, z_8$). A multiple regression is then run with these 16 data points as follows:

$$z_i = a + bi + cH(i),$$

where $H(i)$ is the Heavyside step function (zero for $i \leq 0$, one for $i > 0$). The coefficient "c" now represents our estimate of the net jump produced by the relocation (discounting for the net linear trend which is represented by "b"). The t-statistic is "c" devided by its standard deviation.

*The seasonal adjustment factors are computed as follows:

$$f_{\text{nth quarter}} = \frac{\overline{z} \text{ for all 16 values}}{\overline{z} \text{ for the 4 nth quarter values}}$$

The regression test is explicitly designed to discount for the gradual trend in the data. However, it suffers from the possibility that distortions could be produced by the intercorrelation ($R = 0.89$) between the "independent" variables, "i" and "H(i)".